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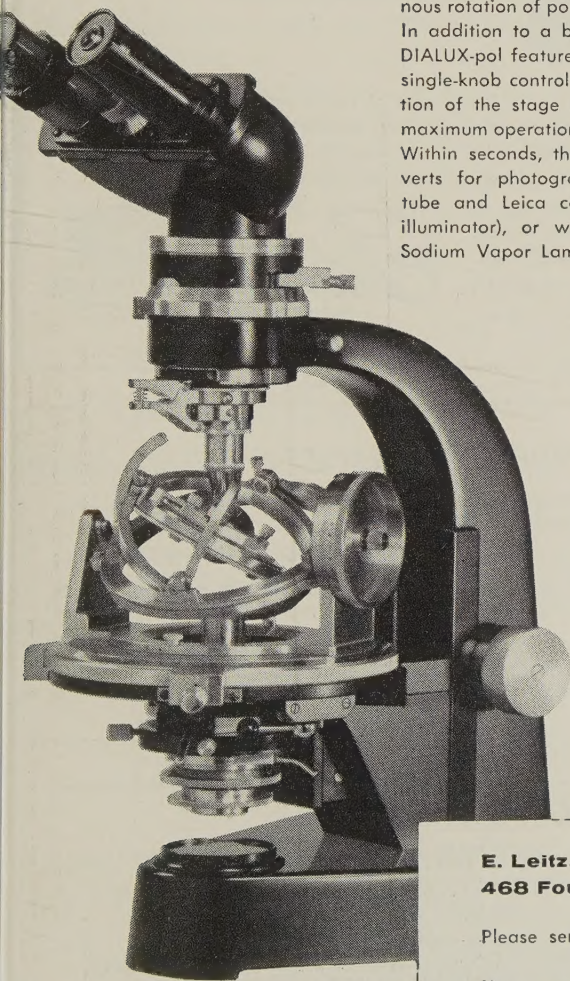
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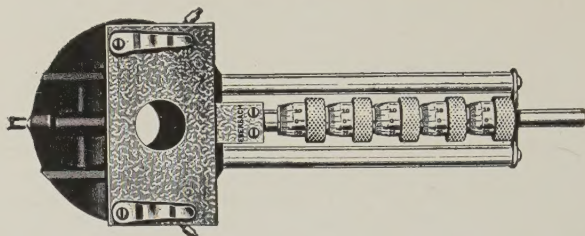
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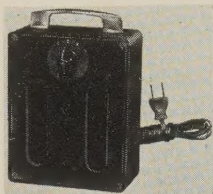
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PEGMATITE PHOSPHATES AND THEIR PROBLEMS*

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ABSTRACT

After an introduction with a few historical comments the writer deals with the matter of nomenclature (illustrated by apatite), including brief remarks on the use of the word *isomorphism*. The pegmatite phosphates are then discussed in terms of 70 species, presented in four tables showing their chemical compositions; the separation into four tables is based on quasi-genetic grounds. Following remarks concerned with crystal structure and crystal chemistry of the mineral phosphates, the paper is concluded with a section giving data in tabular form showing the present status of x-ray studies of the pegmatite phosphates, both single crystal and powder diffraction; the latter is illustrated with 60 photographs. A final Table 8 serves as an alphabetical index to Tables 2 to 7.

INTRODUCTION

As a college student of mineralogy I was greatly impressed with the large amount of space given in *Dana's Textbook* to phosphates, though actually we worked with only a half dozen of them. The majority of recognized phosphate species are found in pegmatites, and indeed in presumed magmatic ones of granitic or syenitic derivation. Unless specifically stated otherwise, all reference to pegmatites in this paper is only to the granitic type. A pegmatite is a rock characterized especially by its texture and structure, composition, and mode of occurrence. In most cases the field geologist raises no questions as to whether he is dealing with a pegmatite or not. Moreover a phosphate is a compound that can be identified readily as such by the delicate and sensitive ammonium molybdate test, which is highly satisfactory on either a macro- or micro-scale. Thus on the whole it is plausible to try and isolate and talk about the little corner of nature which we designate the pegmatite phosphates.

If all you know about phosphates is what you learned in your college course in mineralogy, the only ones you have probably heard of besides apatite, phosphate rock, pyromorphite, etc., are amblygonite, monazite, turquoise, vivianite, and wavellite; though there is an outside chance of

* Address of the retiring President of the Mineralogical Society of America at the thirty-eighth meeting of the Society at Atlantic City, New Jersey, November 5, 1957.

lazulite and triphylite also. You will be disappointed if you expect my talk this afternoon to make up for the phosphate deficiencies of your otherwise liberal education, or even just the pegmatite phosphate deficiencies. I have no time to explain how unique these minerals are; for instance there is an orthorhombic phosphate (childrenite) reported to have monoclinic optics, and a monoclinic phosphate (beryllonite) with orthorhombic optics.

I first became seriously interested in the pegmatite phosphates in 1941. In those pegmatites which carry phosphates, the latter are generally rather prominent, because of their unusual appearance (colors, stain, nodular character, etc.) though they are with few exceptions distinctly minor from a quantitative point of view. Recently on looking over my old notes I was amazed to find to what effort I went to identify these minerals. Tables compiled from Larsen & Berman (U.S.G.S. Bull. 848) were my main stand-by. But even so, there were many substances I was unable to determine in a way which left me satisfied. Perhaps nowhere is the relative backwardness of the study of mineral phosphates more clearly shown than in connection with atomic structure studies. Bragg's well-known book *Atomic Structure of Minerals* of only 20 years ago listed just one such mineral, apatite. To this was devoted $1\frac{1}{4}\%$ of the space allotted to silicates (under which two sentences were given to another phosphate, xenotime).

All this has changed greatly since then. With the work on the Varuträsk pegmatite by Quensel, Mason, and others, with the appearance of the Strunz *Mineral Tables*, Volume II of *Dana's System*, and the second Hintze *Ergänzungsband*, one is easily briefed on a tremendous amount of new pegmatite phosphate data.

The pegmatite phosphates are mineralogical step-children. Being in the main of no economic importance, they are only a pain-in-the-neck to the operator or even to the average economic geologist. The mineralogist examining a pegmatite may find all the good phosphate samples in one portion of the dump. They were thrown there with disgust from a nest-like occurrence in many cases. The operator doesn't like to talk about them. One can only hope that some of the lumps will also carry good samples of the associated minerals, so that worthwhile paragenetic observations can be made. At present the study of their crystallography is in an early mature stage, but tremendous strides have been made in the last quarter century. Combination of good optical, x-ray, morphologic, chemical, and physical work has established beyond question the validity of quite a number of species; but many others are still in a doubtful or problematical state. To judge from published reports, one can consider thin-section work on these minerals as little more advanced than

that on the silicates was at the turn of the century. Much of this should be done on sections cut from samples on whose individual minerals x-ray, chemical, and immersion oil studies have been made.

NOMENCLATURE

An important "human" problem in connection with the pegmatite phosphates—as indeed with all other classes of minerals—is tied in with nomenclature. It is not my purpose to discuss this in great detail, but in

TABLE 1. APATITES— $A_{10}(XO_4)_6Z_2$

Composition	Names	Composition	Names
1. Alkali (Alk)	<i>Dehrnite</i> <i>Lewistonite</i>	9. Lead	<i>Pyromorphite</i> * <i>Mimetite</i> * (As)
2. Aluminum		10. Mangan	
3. Arsenic	<i>Svabite</i> * (Pb) <i>Fermorite</i> (Sr)	11. Oxy*	Voelckerite (Mn)
4. Barium	cf. <i>Hedyphane</i> (As, Pb)	12. Rare-Earth (RE)	Britholite* (Si)
5. Carbonate* (Car)	Francolite	13. Silico	<i>Ellestadite</i> * (S)
6. Chlor*		14. Strontium	Saamite, Belovite
7. Fluor*		15. Sulfo	<i>Wilkeite</i> * (Si)
8. Hydroxyl*		16. Vanadium	<i>Vanadinite</i> * (Pb)

* The 12 species of Strunz (1957), who calls fluor-apatite simply apatite. The 14 species of Dana (Vol. II, 1951) are italicized.

order to clarify some of the statements made later, it is necessary for me to indicate how I deal with this subject. For example, let us take the most common phosphate—apatite. I am no expert on this mineral group; what I have to say is to be considered only as a means of illustration to make a point.

Table 1 shows some members and possible members of this group. The 16 sub-divisions are of course arbitrary; the number could be increased or decreased. Calcium and phosphorus are regarded as too standard to need listing. The handy term *collophane* is omitted. Moreover the subdivisions are not clean cut; the apatites are well known scavengers so far as selection of their component elements is concerned. To a slight extent this is indicated in the table by adding the symbols of certain chemical elements in parentheses after the mineral names.

The question is, how many mineral species are we dealing with, and where will we draw the more or less arbitrary subdividing lines? Dana's *System* splits them into three series, as follows: apatites (with 4 species), pyromorphites (with 3 species), and the roughly intermediate svabites

(with 2 species); in addition there are five miscellaneous species outside of these three series. The fourteen Dana species are italicized in Table 1. Strunz (*Mineralogische Tabellen*, 1957) divides the apatite group into twelve species in four series; three of these are the same as Dana, except the apatite series also includes oxy-apatite and the svabite series has but one member; the fourth series of Strunz is the silicate series with three species (ellestadite, wilkeite, and britholite), the last of which is not given species rank in Dana. Chudoba (*Hintze: Erg. II*, 461, 1955) who follows the classification of Strunz, lists 29 names introduced since the 1933 volume (41, p. 487) of Hintze, which had 12 names with only four of species rank. Of these 29, there are three (abukumalite, britholite, and oxyapatite) which are regarded as well-established species that are not given this rank in *Dana's System*.

Some of the 29 names listed by Chudoba which do not appear in Table 1 are significant in this connection. These include alkali oxyapatite, cerapatite, fluormanganapatite, fluoroxyapatite, manganhydroxyapatite, manganvoelckerite, strontiumarsenic apatite, yttriumapatite, calcium-pyromorphite (collicite), phosphormimetite (campylite), cuprovanadinite, barium hedyphane, calciumbariummimetite.

It seems to me these double-compound names almost give the answer to our question. It is clear that the next step may be triply-compound names such as manganhydroxyfluorapatite for a sample from the Varuträsk pegmatite (*Dana II* 883, no. 4). My simple suggestion for dealing with this subject is to have one species—*apatite*. If in a given paper one wishes to characterize a certain kind of apatite by using more than one chemical prefix; e.g., instead of fluorapatite he wishes to designate carbonate-fluorapatite, he may use this long term once, putting "Car. F apatite" in parentheses after it, to show that throughout the remainder of the paper where he uses Car. F apatite, he means carbonate-fluorapatite.

The apatites may show chemical variation in three ways: 1) in terms of the cations, *A*; 2) in terms of $Z = \text{F, Cl, OH}$ (and O, S? , and $\text{CO}_3\text{?}$); and 3) in terms of *X*, the ion at the center of the tetrahedral group. It is possible that the *X* position can be occupied in whole or part by Al, As, B, C, Ga, P, Si, S, and V. Although little seems to be known about aluminum in apatite, by heating the rare pegmatite phosphate morinite $[\text{Ca}_4\text{Na}_2\text{Al}_4(\text{F}_6\text{O}_2)(\text{PO}_4)_4 \cdot 5\text{H}_2\text{O}]$ the writer has recently produced a fluorapatite that contains some 26% of Al_2O_3 and 8% of Na_2O ; it seems reasonably certain that at least a part of this aluminum is in tetrahedral coordination. This apatite is stable over the range 400 to 800°; at about 800° it inverts to a whitlockite structure of the same composition, from which at about 900° corundum begins to separate.

With the composition of the apatites viewed in this broad way, it

seems that the mineralogist will defeat himself if he insists on giving a non-chemical name to each of these potential apatites. His subdivisions would not only have to be arbitrary; they would approach infinity. Even the twin tetrahedra that Johannsen used for his igneous rock classification with their numerous pigeon-holes would be quite inadequate. We mineralogists are occasionally asked "How many minerals are there?" Are there 300 quartz minerals? In the case of apatite it seems to me our only chance of agreement is to say there is just one; we are not likely to settle on any other number.

It should be made perfectly clear that it is realized there may be some value in retaining certain of the non-chemical names among the apatites, and particularly those of the members of Dana's pyromorphite series; their mode of geologic occurrence as well as their high lead content separates them in distinct fashion from most other members of the group. However this is hardly essential; thus Machatschki's use of lead apatite for the phosphate member in place of pyromorphite has much to be said in its favor.

It seems probable that every working mineralogist realizes the tremendous impact that x-ray crystallography has had on our science for the past quarter-century and more. But sometimes it is not clear that those who like to immortalize the names of their friends have really grasped the full significance of this epochal technique. As in using the polarizing microscope, only a few tiny grains of a mineral are needed; the result is a powder diffraction pattern. While it may not be possible to deduce the structure from this, whether it is isotypous with some known substance or not can be recognized as a rule. The thesis here advocated is in effect that if two or more chemically similar minerals have the same type of structure with approximately the same dimensions, it would be valuable if this could be implied in the name given them. Let it be emphasized that the lone structure concept can be pushed too far; there would be little sense in speaking of the isotypous halite and galena in terms of some name that indicated they had like structures. In short, particularly when dealing with substances having high symmetry, the question of mutual partial or complete solid solubility becomes perhaps increasingly important. There is no attempt here to lay down hard and fast rules; only the plea that all factors be taken into account when introducing a new term.

Chudoba notes that 2142 new names have been added to the literature in the two *Ergänzungsbände* of Hintze. Of these he considers that only 597 or nearly 28% may represent what he designates as valid new species; it is my opinion that this is a somewhat liberal figure. Of the 70 pegmatite phosphate minerals listed in my Tables 2-5, Dana's 1892 *System* gave 31 and the 1951 volume has 60. The rate at which attempts

were made to add names to phosphate minerals is shown in the following tabulation taken from Spencer's lists in the *Mineralogical Magazine* covering the period 1901-1955 (the superscripts show the number of compound phosphates):

Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.
13	3	18	5 ¹	23	6 ¹	28	4
14	8	19	11 ²	24	12	29	13
15	5	20	14 ²	25	14 ¹	30	16 ¹
16	15	21	5 ¹	26	11 ¹		
17	10 ¹	22	11	27	6 ¹	Total	169

While on this subject, I wish to make some remarks on the use of the term "isomorphism." As first employed by Mitscherlich in 1819 following his study of the alkali phosphates, this concept was based on analogous chemical composition and substantially equal interfacial angles, though shortly thereafter he added the idea of vicarious elements introduced by Fuchs in 1815. The physico-chemical term *solid solution* was first used by van't Hoff in 1890. And yet today it is often common to speak of isomorphism meaning solid solution. Thus a few years back our Journal carried an article dealing with isomorphism in the chromites. But obviously the term isomorphism as now understood in any morphologic sense is meaningless when applied to isometric substances. We should revise our use of terms to take account of the advances made in knowledge of the electronic structure of the elements, the nature of the bonds, ionic radii, and x-ray crystallography in general, and we should be careful to use the term *isomorphism* only when crystal morphology also enters into consideration. There are many examples of isomorphous relationships (including of course "analogous" chemical composition) involving little or no solid solution; and there are substances mutually soluble in the solid state which are not isomorphous. It has been known for at least 130 years that calcite and soda niter are isomorphous; it has been clear for 37 years that they are isostructural; but they show no mutual solid solution. If we employ the term *isomorphism* to mean solid solution, what will we use when we want to speak of the phenomena designated by the word *isomorphism* when no solid solution is involved? Isomorphism, isotypism,* and solid solution are terms that have respectively a

* In America it seems to be common to prefer *isostructural* rather than *isotypous*. The two are commonly taken to have the same meaning. It might be well to speak of the apatites as being isotypous but not quite isostructural (assuming the Cl and F occupy different positions in the lattice). Similarly triphylite, lithiophosphatite (Li_3PO_4) and heterosite are isotypous, but not quite isostructural in the strictest sense.

TABLE 2. PRIMARY PHOSPHATES

	Fe''—Mn''	Al—Fe'' '	Be	Other
Li	Natrophilite* Triphylites	Amblygonites		Rare Earths { Monazites Xenotime
Na	Alluaudites (Fe''') Dickinsonites	Bøggildite* (Sr, F)	Beryllonite	Sil- icon { Nagatelite Lomonosovite*
Ca	Griphite (Al) Graftonite			Apatites (etc.)
Other	Triplites (F, Mg) Triploidites (OH)	Lazulites (Mg, Fe'')		

* Known from only one occurrence (lomonosovite is from a syenite pegmatite).

TABLE 3. LATER PHOSPHATES*

	Fe''—Mn''	Al	Be	No Other
Li				Lithiophosphatite†
Na	Fillowite†	Palermoite† (Sr, OH) Brazilianite (OH) Morinite‡ (F, OH) (Lacroixite)†		
Ca	Fairfieldites‡	Roscherite‡ (Mn'', Fe'')	Herderites (OH, F) Hurlbutite	Whitlockite
Mg	Sarcopside (F) Ludlamite‡	Souzalite†‡ (Fe'', Fe'' ', OH)		Isokite (F)
Other	Reddingites‡ Hureaulite‡	Augelite (OH)	Moraesite†‡ (OH) Väyrynenite† (Mn, OH) Faheyite†‡ (F''', Mn'')	
	Childrenites‡ (OH)			

* The F-phosphates spodiosite and wagnerite have not been found in pegmatites; neither have the Al phosphates berlinite, kolbeckite (Be), tavistockite, and svanbergite (or hinsdalite).

† Known from only one occurrence; souzalite is a hydrothermal alteration product of scorzalite (a ferro-lazulite).

‡ Contains H₂O.

TABLE 4. SUPERGENE PHOSPHATES*
(not known outside of pegmatites)

	Mn''—Fe''	Mn''—Fe''	Zn
Li	Sicklerites*		
Ca			Scholzite†
Mg		Bermanite† (Mn'')	
Other			Phosphophyllite† (Fe'', Mn'')
No	Kryzhanovskite†	Heterosites*	
Other	Landesite Pseudolaueite† Salmonsites† Stewartite Xanthoxenite		

* All carry H₂O (not indicated in the Table) except heterosite and sicklerite; the latter may be of epithermal origin, as may pseudolaueite, stewartite, and some others.

† Known from only one occurrence.

TABLE 5. SUPERGENE PHOSPHATES*
(known occurrences not limited to pegmatites)

	Fe''	Al	Pb, Zn	U
Na	Wardites			
Ca		Ca Goyazite		Ca Torbernite Phosphuranylite
Fe''	Frondelites (Mn'') Vivianite (no Fe'')		Parahopeite (Zn)	
Other	Paravauxite (Mg, Mn'') Koninckite (Mn'') Leucophosphite (K)	Sr Goyazite Ce Goyazite Wavellite (OH)	Pyromorphite (Pb, Cl)	Cu Metatorbernite Cu Torbernite
No	Beraunite	Evansite	Parsonsite (Pb)	
Other	Cacoxenite Fe'' Metavariscite Fe'' Variscite	Vashegyite	Hopeite (Zn)	

* All carry H₂O (not indicated in the table) except pyromorphite; only (OH) in frondelites.

morphologic, a structural, and a crystallo-chemical or physico-chemical connotation; let us keep them that way.

THE PEGMATITE PHOSPHATES

But what has all this to do with the subject of this paper? Well, just this. Considered in the standard fashion one might say that there are about 105 established phosphate species known to occur in pegmatites; these include those phosphates which are found in pegmatites which have been subjected to more or less minor alterations under supergene conditions, but they omit the names of many very doubtful or unsatisfactorily described species. On the other hand, if we throw out what may be regarded in terms of the principles already covered as unnecessary or nonessential names, this number is reduced by 35, and thus amounts to only 70 species. Thus decreased by one third, it is more readily possible to make some remarks having in view the forest as a whole in spite of all the trees that are present.

Phosphorus is the eleventh most abundant element (after titanium and hydrogen) by weight in the earth's crust. It is estimated that at least 95% of the phosphorus in igneous rocks (mostly in those of the basaltic clan) is in the ubiquitous apatite. While this is perhaps the commonest phosphate mineral in granitic pegmatites, it is likely that in this environment both triphylites and amblygonites occur in greater amounts. Quantitatively speaking, it is known that pegmatites constitute an insignificant part of the lithosphere, and phosphates comprise a trivial volume of the great mass of pegmatites.

The large number of individual phosphate minerals occurring in certain pegmatites, as well as the rarity of many of them (at least seventeen are at present reported from only one locality) has been a drawback to their study. The beginner is overwhelmed; he hardly knows where to start. As late as 1930 the great Russian pegmatite mineralogist A. E. Fersman shuddered at this subject. At that time he dealt with only 35 phosphates, yet when he discussed the role of phosphorus in pegmatites he limited himself to a brief one-sentence paragraph concluding with the statement "the history of phosphorus is of the greatest interest and needs special investigation." Twenty-three of these phosphates were included in his hypercritical stage *G*; five were under more intense conditions, and seven under less intense.

The geologist interested in the origin of a given rock type, such as a granite pegmatite, would not select for genetic study some common accessory group of minerals occurring in this rock, with the expectation that his results would be of much significance from the larger point of view. Thus from the study of phosphates one could hardly hope to con-

clude much of a definitive nature as regards the broad question of the origin of pegmatites. But one is bound to fill in something on the natural history of a rock, even from the study of a "trace mineral" category. The large number of phosphate species simply points up the relatively limited range of stability of any one phosphate in general. Many of them can be considered as delicate indicators of the particular conditions present at the time of their formation. While dealing in general with much less than one per cent of the pegmatite mass, we may be working with a score or more of minerals all told. Thus as primary ones give way to secondary and even tertiary species—and possibly to supergene ones—we have conditions in existence of more or less temporary approximate equilibrium for one or another phosphate.

But let us proceed from the general to the specific. In Tables 2-5 my seventy phosphate species have been arranged in a fairly arbitrary but crudely genetic set of four divisions. These include what have been designated 1) primary, 2) later, and 3) supergene, the latter split into two categories depending on whether the known occurrences are limited to pegmatites or not; obviously as phosphate study proceeds, some or all of those listed in Table 4 will be transferred to Table 5.

Phosphates occur in any of the shells of zoned pegmatites, but those with important amounts generally carry most of the phosphate in an intermediate zone or a replacement unit. The 18 phosphates designated as primary (listed in Table 2) are those which typically occur in pegmatites in more or less large masses (exceptions are noted later). These are commonly in crudely spherical or ellipsoidal masses with a fringe of alteration product as a border. They generally seem to be somewhat corroded single crystals, not uncommonly of giant dimensions; they often have the appearance of nodules.

It should be emphasized that many of the minerals listed in this table occur in some pegmatites as a later formation. For example, what is now known as ferro-dickinsonite (arrojadite) was described by Headden in 1891 from a Black Hills pegmatite; here it occurred in large masses carrying cassiterite, and was obviously primary. Mangan-dickinsonite may be in part primary at Branchville, Conn., but at Poland, Me. it occurs as later crystals lining vugs. Similarly amblygonite, while often primary, is well known also as small crystals lining vugs. Quensel puts alluaudite in his supergene stage at Varuträsk; nevertheless, in some of its occurrences it is definitely a primary mineral. Apatite may be found in any of the zones of a pegmatite, in a replacement unit, or as needles shooting across vugs. In order to avoid repetition, no species is listed in more than one of the tables. It should also be recognized that probably rarely some phosphates listed in Table 3 may occur in small amounts in a given deposit as a pri-

mary mineral. The really typical primary phosphate minerals of the pegmatites are those shown in the first column of Table 2 (less natrophilite, known only from Branchville) plus amblygonite, and the rare-earth phosphates. Of course apatite is also commonly primary, but it and all of the others of Table 2 not specifically mentioned here do not occur as relatively large masses so typical of the characteristic primary phosphates.

It should be emphasized that the so-called primary phosphates listed in Table 2 are not limited to the original minerals of the various zones. Thus Shainin considered that at Branchville the manganese phosphates occur in one of three replacement units; in fact the smallest one, the cleavelandite-spodumene unit. Natrophilite is regarded as primary here because of its close association with mangan-triophyllite; fillowite is placed in Table 3 because of its close association with reddingite. Beryllonite is included in Table 2 (rather than Table 3) since it is recognized by Volborth as being the first beryllium phosphate to be formed at Viitaniemi, Finland, where it occurs in a replacement unit; hydrothermal action altered part of it to hurlbutite, and part of the latter to herderite. Ferrolazulite (scorzalite) has been found in the wall zone of a Black Hills pegmatite.

Table 3 lists 20 "later" phosphates; these are commonly considered to be of hydrothermal origin, but since many of those given in Table 2 may also be of this origin, the term is not applied. In certain deposits some of these are considered to be hydrothermal alteration products of one or more of the phosphates of Table 2. An attempt was made to separate the hydrous phosphates from the others, but this did not seem to yield results of genetic significance; accordingly a footnote is used in Tables 3 and 4 to set off the hydrous phosphates. It is probable that the hydrous minerals of Table 3 are in general lower-temperature, and therefore later, than those lacking water. Those phosphates which contain ferric iron (unless it proxies for aluminum) are excluded from Table 3; this has been shown by Mason to have real genetic significance. However vivianite (Table 5) normally lacks this cation, and the alluaudites (Table 2) always carry it.

Tables 4 and 5 contain those phosphates regarded as commonly supergene. However, some of the eleven minerals in Table 4 (see the footnote) may certainly be of epithermal origin. These are included in this table because of their ferric iron content; it is thus admitted that the heading for this table is used loosely. It is also true that vivianite, frondelites, wavellite, and probably others of the 21 given in Table 5 may be of epithermal origin. It is of course very difficult or impossible to draw a sharp line between epithermal and supergene; Quensel puts it at 100° C., though 50° C. is a more common figure. But even if some arbitrary defi-

nite temperature is set, our state of knowledge is insufficient to place all these phosphates on the proper side of the boundary line. If one should choose to split the post-primary and non-supergene pegmatite phosphates into two categories: 1) hypo- and mesothermal, and 2) epithermal, it is certain that the latter would contain a number of species here put in Tables 4 and 5.

PHOSPHATE STRUCTURES AND CRYSTAL CHEMISTRY

Structures among the phosphates are in some cases analogous to those of the silicates and other minerals, but the structural work on phosphates has never had a Bragg. Nesophosphates (that is, orthophosphates, island structures) seem to be by far the most common; volume II of *Dana's System* is practically all in terms of orthophosphates. Sorophosphates (that is, pyrophosphates, group or doublet structures), cyclophosphates (tetrametaphosphates, four-ring structures), and inophosphates (tetrametaphosphates, single chain structures) are known, but not among minerals. These condensed phosphates are relatively unstable; in solution they hydrolyze readily to orthophosphates.

Phyllophosphates and tektophosphates in which phosphorus is the only tetrahedral cation are non-existent in nature.* Since phosphorus in oxygen salts has a valence of +5 and is in tetrahedral coordination, the phosphates are by definition anisodesmic; each P—O bond has an average charge of 5/4. In short, the oxygens are held more tightly to the phosphorus (and less tightly to the other cations) in phosphates than is true for silicates; thus the phosphates are in general softer than the silicates, because of the relatively weaker oxygen-cation bonds in the former. If two PO_4 groups are joined through a common oxygen, this ion would on the average (assuming regular non-resonating tetrahedra) have two bonds each of electrostatic charge 5/4; in short an excess charge of 1/2. It is to be noted that the sorophosphate $\text{Mg}_2\text{P}_2\text{O}_7$ (isotypous with thortveitite) has highly distorted PO_4 tetrahedra, and the PO_4 chains in rubidium metaphosphate (RbPO_3) are spirals; in short polymorphism in the phosphates is very different from that in the silicates.

On the other hand, a PO_4 group can share one or more of its oxygens with an AlO_4 group, or in general with any tetrahedral group in which the central cation has a charge of 3 or less. Cations of this nature known to occur in tetrahedral coordination include beryllium, boron, aluminum and gallium. Thus when these metals are present in phosphates, structures of the sheet or framework type are possible. An example of the former is the monoclinic herderite $[\text{Ca}(\text{BeP})(\text{O}_4\text{F})]$, isotypous with dato-

* The rings of six or ten PO_4 tetrahedra in the orthorhombic modifications of P_2O_5 are united into net or framework structures quite different from those in the silicates.

lite $[\text{Ca}(\text{BSi})(\text{O}_4\text{OH})]$, which has infinite sheets of alternating BO_3OH and SiO_4 tetrahedra parallel (100); these are linked tightly by calcium in 8 coordination. Representative of the latter are orthorhombic hurlbutite ($\text{CaBe}_2\text{P}_2\text{O}_8$), isotypous with danburite ($\text{CaB}_2\text{Si}_2\text{O}_8$) and also the pseudo-orthorhombic feldspar paracelsian ($\text{BaAl}_2\text{Si}_2\text{O}_8$); and rhombohedral berlinite (AlPO_4), isotypous with quartz; (AlPO_4 also has phases corresponding to tridymite and cristobalite). In addition the monoclinic beryllonite (NaBePO_4) is homeotypous with trimerite $[(\text{Ca},\text{Mn})\text{BeSiO}_4]$, which may be a framework structure. It should be noted that in the well-known layer structure seen in the torbernites and metatorbernites, the sheets contain not only PO_4 groups, but also UO_6 groups; in short here the PO_4 groups exist as islands.

Examples of nesophosphate-nesosilicate isotypous pairs include xenotime-zircon, monazite-huttonite, triphylite (also sicklerite, heterosite, lithiophosphatite, and nearly natrophilite)-olivine, libethenite-andalusite, and isokite-sphene. Phosphorus may also replace some of the silicon of silicates, and *vice versa*; the apatites, most abundant of phosphates and those on which most structural work has been done, are examples of the latter, as is kolbeckite; representative of the former are viséite (anal-cime structure), erikite, nagatelite, and the recently described pegmatite mineral lomonosovite.

Other mineral phosphates whose structures have been determined include ludamite, monetite, vivianite, and possibly whitlockite. Additional structures are known among the closely-related arsenates; these include berzeliite (garnet structure; cf. griphite), scorodite (variscite is isotypous), brandtite, and pharmacosiderite. Strunz (1957, p. 56) has hematolite isotypous with the rare As silicate dixenite. Less commonly phosphate-sulfate isotypous pairs have been recognized. These include brushite/churchite-gypsum and the goyazites*-alunites; the svanbergites† contain equal amounts of the two; i.e., they are phosphate-sulfates. Combinations are known of phosphate with borate (luenebergite, seamanite), carbonate (bradleyite), and nitrate (likasite). With the possible exception of the borates, these seem to be analogous to double salts. Sin-cosite may be a meta-autunite with vanadium in place of uranium.

In summary it is clear that a fair start on the elucidation of phosphate structures has been made, but that a tremendous amount of work remains to be done. The discussion in this section has not been limited to the pegmatite phosphates.

* Dana (II 831) calls these the plumbogummmites. The group was formerly known as the hamlinites, but the latter mineral has been shown to be goyazite. The name *plumbogummite* is quite unsatisfactory, since the mineral is not gummite (*Am. Mineral.* **41**, 1956, 539-568).

† The writer uses this term to include the four phosphates of the beudantite group.

TABLE 6. CRYSTALLOGRAPHY OF THE PEGMATITE* PHOSPHATES

Triclinic System (with $c < a < b$); space group $P\bar{1}$

a/b	c/b	a_0 α	b_0 β	c_0 γ	Strongest line (Å)	Name
0.684	0.515	6.97 101°34'	10.19 111°12'	5.25 96°55'	9.6 9.93 —	Gordonite (laueite) (paravauxite)
0.729	0.708	5.19 112°03'	7.12 97°50'	5.04 68°08'	4.62 3.14 2.97 3.29	Amblygonite (fremontite) (montebrasite) (tavorite)
0.764	0.702	5.77 93°18'	7.55 91°55'	5.30 91°19'	—	Parahopeite
0.880	0.834	5.78 102°05'	6.57 108°43'	5.48 90°05'	3.22 3.14(6.34)	Fairfieldite (messelite)

Monoclinic System (with $c < a$ for ratios)

a/b	c/b	a_0	b_0	c_0	β	Space group	Strongest line	Name
.171	.118	7.17	60.8	10.41	109–32	—	10.05	Stewartite
.232	.193	8.55	36.90	7.13	97–41	15– $C2/c?$	7.00	Morassite
.541	.894	5.29	9.77	8.73	90–36	11– $P2_1/m$	2.78	Clinostrengite
.545	.894	5.16	9.47	8.47	90±	11– $P2_1/m$	2.72	Clinovariscite
.727	.330	10.47	14.40	4.75	102–49	14– $P2_1/a?$	3.42; 2.84	Väyrynenite
.751	.350	10.08	13.43	4.70	104–30	12– $C2/m$	6.59	Vivianite
.767	.533	8.87	11.57	6.17	99–12	14– $P2_1/c$	2.86, 3.50	Graftonite (magniophilite)
.838	.529	5.34	10.09	8.46	90–40	—	—	Kolbeckite*
.859	.745	7.51	8.75	6.52	121–28	15– $C2/c$	3.18	Isokite
.868	.518	10.93	12.59	6.52	97–59	15– $I2_1/a$	2.72	Hagendorffite
.880	.511	11.03	12.53	6.40	97–34	15– $I2_1/a$	2.71 2.72	((hühnerkobelite) Alluaudite (varulite)
.885	.509	9.46	10.69	5.45	105–28	11– $P2_1/m$	2.73 2.95	Morinite
.896	.512	—	—	—	105–32	—	2.95	Jezekite
.916	.740	12.26	13.38	9.90	108–04	14– $P2_1/a$	2.92	Triploidite
.921	.739	12.12	13.16	9.73	108–18	14– $P2_1/a$	2.93	Wolfeite
.951	.770	11.92	12.53	9.65	108–07	14– $P2_1/a$	2.95	Wagnerite*
.963	.919	6.74	7.00	6.43	104–36	14– $P2_1/n$	3.07	Cheralite
.964	.919	6.79	7.04	6.47	104–24	14– $P2_1/n$	3.05	Monazite
.977	.975	7.15	7.32	7.14	119–00	14– $P2_1/n$	3.25	Scorzalite
.983	.981	7.12	7.24	7.10	118–55	14– $P2_1/n$	3.23	Lazulite
1.014	1.009	9.73	9.60	9.69	102–16	14– $P2_1/n$	3.36	(barbosalite)
1.110	.700	11.19	10.08	7.06	97–22	14– $P2_1/n$	6.78	Leucophosphite
1.275	.625	9.82	7.70	4.81	90–06	14– $P2_1/a$	5.04	Brazilianite
1.364	1.285	9.57	7.45	10.16	104–40	—	3.11	Herderite
1.645	.635	13.13	7.98	5.07	112–27	12– $C2/m$	9.93	Pseudolaueite
1.767	.500	5.24	10.48	18.52	107–35	14– $P2_1/c$	3.33	Augelite
1.807	1.047	8.16	7.79	14.08	90–00	14– $P2_1/n$	3.16	Bøggildite
1.862	1.553	12.05	6.47	10.05	105–42	12– $I2/m$	2.81	Beryllonite
1.864	1.552	12.02	6.45	10.01	108±	12– $I2/m$	2.87	Triplite
1.910	1.042	17.42	9.12	9.50	96–40	13– $P2_1/c$	2.87? 3.14	Zwieselite Hureaulite
2.065	2.014	10.25	5.09	10.51	120–15	14– $P2_1/c$	2.85, etc.	(salmonsitite?)
2.247	1.989	10.45	4.65	9.25	100–30	14– $P2_1/a$	2.83	Phosphophyllite
2.462	1.650	16.68	10.11	24.89	105–41	15– $C2/c$	2.55	Ludlamite
2.484	1.657	16.60	10.02	24.89	105–50	15– $C2/c$	3.02	Dickinsonite
3.998	3.734	20.59	5.15	19.23	94–06	15– $C2/c$	3.04	Arrojadite
Data lacking							10.30	Beraunite
							3.14 etc.	Kryzhanovskite
							2.91	Lacroixite?
							—	Lomonosovite?
							—	Nagatelite
							3.22	Parsonsite
							9.59	Roscherite
							2.69	Souzalite?
							(Syst. not known)	Xanthoxenite?

* Including *ca.* 7 hydrothermal species marked with an asterisk.

TABLE 6 (continued)

 Orthorhombic System (with $c < a < b$ for ratios)

a/b	c/b	a_0	b_0	c_0	Space group	Strongest line (Å)	Name
.455	.329	6.26	8.94	19.65	—	9.59	Bermanite
.555	.403	9.62	17.34	6.99	62- <i>Pcmn</i>	8.40	Wavellite
.580	.275	18.36	5.04	10.64	62- <i>Pmcn</i>	2.85	Hopeite
.580	.452	10.36	4.68	6.01	62- <i>Pnam</i>	2.53	Triphylite
						2.53	(lithiophilite)
.587	.467	10.24	4.78	6.01	62- <i>Pnam</i>	3.01, 2.53	Sicklerite (Mn)
.589	.475	10.11	4.80	5.95	62- <i>Pnam</i>	2.95, 2.49	Sicklerite (Fe)
.601	.492	9.70	4.77	5.83	62- <i>Pnam</i>	2.45	Heterosite
						2.45?	(purpurite)
.601	.472	10.54	4.98	6.33	62- <i>Pnam</i>	2.60	Natrophilite
						3.98	(lithiophosphatite)
.730	.463	7.31	15.79	11.53	71- <i>Immm</i>	3.11	Palermoite
.772	2.98	17.14	22.19	6.61	51- <i>Pbmm</i>	8.59	Scholzite
.775	.514	10.45	13.49	6.93	41- <i>Bba2</i>	2.82	Eosphorite
.777	.517	10.38	13.36	6.91	41- <i>Bba2</i>	2.81	Childrenite
.812	.306	13.76	16.94	5.19	20- <i>B22,2</i>	3.31	Rockbridgeite
.817	.306	13.89	17.01	5.21	20- <i>B22,2</i>	3.16	Frondeite
.896	1.559	6.17	6.89	10.74	57- <i>Pbcm</i>	2.81	Chlor-Spodiosite*
.910	.790	15.85	17.42	13.76	63- <i>Bmmb</i>	7.83	Phosphuranylite
.915	.783	16.01	17.5	13.7	63- <i>Bmmb</i>	7.95	Renardite
.939	.864	9.41	10.02	8.66	53- <i>Pmna</i>	3.18	Phosphoferrite
.941	.864	9.49	10.07	8.70	53- <i>Pmna</i>	3.20	Reddingite
.942	.888	8.29	8.80	7.81	47- <i>Pmmm</i>	3.67	Hurlbutite
.970	.863	9.87	9.57	8.52	61- <i>Pcab</i>	4.29	Variscite
.979	.860	10.08	9.87	8.67	61- <i>Pcab</i>	4.36	Strengite
		Data Lacking			—	—	Koninckite?
					—	—	Tavistockite*

Tetragonal System

c/a	a	c	Space group	Strongest line (Å)	Name
0.877	6.89	6.04	141- <i>I4/amd</i>	3.42	Xenotime
1.239	6.96	8.62	129- <i>P4/nmm</i>	3.61	Metatorbernite
2.650	7.32	19.4	92- <i>P4,2,2</i>	4.85	Cyrllovite
2.682	7.04	18.88	92- <i>P4,2,2</i>	4.74	Wardite
2.904	7.06	20.5	139- <i>I4/nmm</i>	3.69, 10.3	Torbernite
2.953	7.00	20.67	139- <i>I4/nmm</i>	3.46	Autunite

Hexagonal System

c/a	a_0	c_0	Space group	Strongest line (Å)	Name
0.71-0.74	9.4±	6.9±	176- <i>P6₃/m</i>	2.80	Apatite
0.735	9.97	7.33	176- <i>P6₃/m</i>	2.92	Pyromorphite
1.325	7.92	10.5	—	3.35	Cacoxenite
1.697	9.43	16.0	—	5.72	Faheyite
2.217	4.93	10.94	152- <i>P3₁/2</i>	3.32	Berlinite*
2.308	6.99	16.13	160- <i>R3m</i>	2.92	Crandallite
2.346	6.96	16.33	—	2.92	Koivinite
2.370	6.98	16.54	166- <i>R3m</i>	2.97	Goyazite
2.410	6.97	16.8	166- <i>R3m</i>	2.98	Svanbergite*
2.448	6.76	16.55	—	2.92?	Florensite
2.535?	—	—	—	2.98?	Hinsdalite*
2.841	15.25	43.32	148- <i>R3</i>	2.80	Fillovite
3.57	10.32	36.9	161- <i>R3c</i>	2.85	Whitlockite

Isometric System

a_0	Space group	Strongest line (Å)	Name
12.28	230- <i>Ia3d</i> ?	2.74	Griphite

CONCLUDING REMARKS

Data showing the present status of x-ray studies of the pegmatite phosphates are presented in Tables 6 (single crystal) and 7 (powder diffraction). Table 8 is an alphabetical index to Tables 2 to 7.

TABLE 7. PEGMATITE* PHOSPHATE POWDER DIFFRACTION DATA

Strongest lines			Name	Photo-graph	Locality	Crystal system	a/b (c/a in dimetric)
1.85/10	1.82/10	3.14/10	Kryzhanovskite	—		M	—
2.45/10	2.91/9	1.58/8	Heterosite	1A	Grafton, N.H.	O	0.601
			(Purpurite)	—			
2.49/10	2.95/10	5.01/9	Sicklerite (Fe)	—		O	0.589
2.53/10	3.01/10	4.32/9+	Sicklerite (Mn)	1B	Black Hills	O	0.587
2.53/10	3.01/9	1.75/8+	Lithiophilite	cf. 1C		O	0.580?
2.53/10	3.02/9+	2.49/9	Triphylite	1C	Rochester, N.H.	O	0.580
2.55/10	2.77/9	3.96/8	Ludlamite	1D	Palermo, N.H.	M	2.247
2.60/10	2.87/9	4.05/7	Natrophilite	1E	Branchville	O	0.601
2.69/10	3.79/8?	5.35/7?	Souzalite	—		M?	—
2.71/10	2.53/6	6.26/5	Hühnerkobelite	cf. 1F	Hühnerkobel	M	0.87?
2.72/10	3.05/8	6.26/7	Alluaudite	1F	Chanteloube	M	0.880
2.72/10	6.28/7	2.54/5	Hagendorfite	cf. 1F	Hagendorf	M	0.868
2.73/10	2.54/9	3.49/7	Varulite	cf. 1F	Varuträsk	M	0.87?
2.74/10	3.07/5	2.99/4	Griphite	1G	Black Hills	I	1.00
2.78/10	4.34/9	4.68/8	Clinostrengite	1H	Bavaria	M	0.541
2.80/10	2.70/7	1.90/6	Apatite	1J	Saxony	H	0.71-0.74
2.80/10	3.00/7	2.54/6	Fillowite	1K	Branchville	R	2.841
2.81/10	1.52/8	5.19/7	Childrenite	cf. 2B		O	0.777
2.81/10	3.62/9	2.27/6	Beryllonite	2A	Stoneham, Me.	M	1.807
2.82/10	5.22/7	4.39/7	Eosphorite	2B	Branchville	O	0.775
2.83/10	9.00/8	4.43/7	Phosphophyllite	—	Bavaria	M	2.065
2.84/10	3.42/10	2.64/9	Väyrynenite	—		M	0.727
2.85/10	2.58/8	3.16/7	Whitlockite	2C	Palermo	R	3.57
2.85/10	9.1/9	4.56/7	Hopeite	2D	Rhodesia	O	0.580
2.85/10	9.4/10	3.16/10	Salmonsite	2E	Pala	M?	1.91?
2.86/10	3.50/10	2.72/8	Graftonite	2F	Grafton	M	0.767
2.87/10	3.05/9	3.26/7	Triplite	2G	Bohemia	M	1.862
2.87/10	3.05/9	3.26/7	Zwieselite	cf. 2G		M	1.864
2.92/10	1.52/9	1.49/9	Pyromorphite	2H	Nassau, Ger.	H	0.735
2.92/10	1.88/7	1.28/7	Koivinite	—		R	2.346
2.92/10	2.15/8	1.89/7	Crandallite	2J	Fairfield	R	2.308
2.92/10	3.09/10	3.19/8	Triploidite	2K	Branchville	M	0.916
2.93/10	3.09/9	3.18/8	Wolfeite	cf. 2K		M	0.921
2.95/10	2.49/10	5.01/9	Sicklerite (Fe)	cf. 1B		O	0.589
2.95/10	2.83/9	3.26/8	Wagnerite*	3A	Norway	M	0.951
2.95/10	3.47/9	1.79/9	Morinite	3B	France	M	0.885
2.95/10	3.47/9	1.79/9	Jezekite	cf. 3B		M	0.896
2.97/10	2.20/8	1.89/7	Goyazite	cf. 3C	New Hampshire	R	2.370
2.97/10	5.70/8	3.45/6	Plumbogummite	3C		R	—
2.97/10	4.68/9	3.22/6	Montebrasite	3D	Black Hills	Tr	0.73?
2.98/10	2.22/6	5.75/4	Svanbergite*	cf. 3C		R	2.410
3.01/10	2.81/8	3.49/7	Vashegyite	—	Nevada	—	—
3.01/10	2.53/10	4.32/10	Sicklerite (Mn)	1B	Black Hills	O	0.587
3.02/10	2.72/9	1.77/6	Dickinsonite	3E	Poland, Me.	M	2.462
3.04/10	2.70/9	3.21/7	Arrojadite	cf. 3E		M	2.484
3.05/10	3.26/6	2.85/4	Monazite	3F	New Mexico	M	0.964
3.07/10	2.86/?	3.26/?	Cheralite	cf. 3F		M	0.963
3.11/10	2.85/6	2.20/5+	Herderite	3G	Auburn	M	1.275
3.11/10	4.38/9	2.44/8	Palermoite	—		O	0.730
3.14/10	1.85/10	1.82/10	Kryzhanovskite	—		M	—
3.14/10	2.87/7	3.72/6	Messelite	3H	Hesse	Tr	0.88?
3.14/10	2.98/8	8.01/7	Hureaulite	3J	Branchville	M	1.910
3.14/10	4.62/9	2.95/8	Natromontebrasite	cf. 3D		Tr	0.73?
3.16/10	1.59/7	3.56/6	Frondelite	3K	Brazil	O	0.817

* Including three hydrothermal phosphates (marked with an asterisk) not known from pegmatites.

TABLE 7 (continued)

Strongest lines			Name	Photo-graph	Locality	Crystal system	a/b (c/a in dimetric)
3.16/10	2.85/10	9.42/10	Salmonsite	2E	Pala	M?	1.91?
3.16/10	3.89/9	3.96/8	Bøggildite	—		M	1.767
3.18/10	3.02/8	2.63/7	Isokite	4A	Bohemia	M	0.859
3.18/10	4.97/7	4.25/6	Phosphoferrite	4B	Bavaria	O	0.939
3.20/10	2.62/8	3.15/7	Landesite	4C	Poland, Me.	cf.	reddingite
3.20/10	5.01/6	2.74/6	Reddingite	cf. 4B		O	0.941
3.22/10	3.01/8	6.33/7	Fairfieldite	4D	Branchville	Tr	0.880
3.22/10	3.38/9	4.13/8	Paronsite	—		M	—
3.23/10	4.72/7	3.14/7	Lazulite	4E	Death Valley	M	0.983
3.25/10	3.20/9	3.15/5	Scorzalite	cf. 4E		M	0.977
3.29/10	3.05/9	4.99/5	Tavorite	4F	Brazil	Tr	0.73?
3.31/10	3.20/9	1.60/7	Rockbridgeite (Zn)	4G	Portugal	O	0.812
3.32/10	4.27/4	3.97/3?	Berlinite*	—		R	2.217
3.33/10	3.51/9½	4.72/8	Augelite	4H	Black Hills	M	1.645
3.35/10	12.0/3	4.27/3	Cacoxenite	4J	Arkansas	H	1.325
3.36/10	3.31/8	4.84/6	Barbosalite	4K	Brazil	M	0.98?
3.42/10	1.76/9	0.807/7	Xenotime	5A	Norway	Te	0.877
3.42/10	2.84/10	2.64/9—	Väyrynenite	—		M	0.727
3.46/8	2.16/6	3.23/3	Autunite†	—		Te	2.953
3.51/10	3.90/7	2.81/7	Sarcopside	5B	New Hampshire	—	—
3.61/10	8.57/9	3.42/7	Metatorbernite	5C	Unknown	Te	1.239
3.67/10	3.03/9	2.78/9	Hurlbutite	5D	New Hampshire	O	0.942
3.69/10	1.56/8	1.64/7	Torbernite†	—		Te	2.904
3.98/10	3.79/10—	2.67/8+	Lithiophosphatite	5E	Synthetic	O	0.60?
4.36/10	5.47/9	3.10/8	Strengite	5F	Bavaria	O	0.979
4.62/10	3.15/9+	2.96/9	Amblygonite	cf. 3D		Tr	0.729
4.74/10	2.99/7	2.59/7	Wardite	5G	Black Hills	Te	2.682
4.85/10	3.19/8	2.66/8	Cyrllovite	5H	Brazil	Te	2.650
5.04/10	2.98/8	2.73/8	Brazilianite	5J	Brazil	M	1.110
5.72/10	7.28/9	3.24/6	Faheyite	5K	Brazil	H	1.697
6.34/10	3.17/10	3.02/8	Messelite	3H	Hesse	Tr	0.880?
6.59/10	6.84/5	3.19/5	Vivianite	6A	Colorado	M	0.751
6.78/10	5.96/9	3.06/7	Leucophosphite	6B	Brazil	M	1.014
7.00/10	3.28/9	4.24/6	Moraesite	6C	Brazil	M	0.232
7.83/10	3.97/9	5.83/8	Phosphuranylite	—		O	0.910
7.95/10	3.11/9	2.88/8	Renardite	—		O	0.915
8.40/10	3.60/8	3.48/8	Meta-autunite	cf. 5C	Australia	Te	1.24?
8.10/10	3.20/9	3.44/9—	Wavellite	6D	Arkansas	O	0.555
8.59/10	2.79/9	4.23/7	Scholzite	6E	Bavaria	O	0.772
9.42/10	3.16/10	2.85/10	Salmonsite	2E	Pala	M?	1.91?
9.59/10	5.08/8	2.90/8	Bermanite	6F	Arizona	O	0.455
9.59/10	5.93/9	3.17/9	Roscherite	6G	Rumford, Me.	M	—
9.6/10	6.37/8	4.80/7	Gordonite	cf. 6H	Utah	Tr	0.684
9.93/10	3.28/6	4.92/5	Laueite	6H	Bavaria	Tr	0.684?
9.93/10?	3.28/6?	4.92/5?	Paravauxite	cf. 6H		Tr	0.684?
9.93/10	5.87/7	3.47/4	Pseudolaueite	6J	Bavaria	M	1.364
10.1/10	4.38/7—	6.70/5	Stewartite	—		M	0.171
10.3/10	4.94/9	3.58/9	Torbernite	—	Synthetic	Te	2.904
10.3/10	3.07/8	4.81/7	Beraunite	6K	Arkansas	M	3.998
10.5/10	7.20/7	2.90/7	Vashegyite	—		—	—

 † When fully hydrated, shows strong lines at $d \approx ca.$ 10.0 and 5.0 Å.

TABLE 8. INDEX TO THE PEGMATITE* PHOSPHATES

No.	Name	Strongest line Å	Crystal system	a/b^\dagger (c/a in dimetric)	Occur. (Table No.)
1	Alluaudite	2.72	M	0.880	2
2	Amblygonite	4.62	Tr	0.729	2
3	Apatite	2.80	H	0.71 to 0.74	2
13a	Arrojadite	3.04	M	2.484	2
4	Augelite	3.33	M	1.645	3
58a	Autunite	3.46	Te	2.953	5
66a	Avelinoite		(Same as cyrilovite)		
32a	Barboselite	3.36	M	0.98?	2
5	Beraunite	10.30	M	3.998	5
*	Berlinite	3.32	R	2.217	3
6	Bermanite	9.59	O	0.455	4
7	Beryllonite	2.81	M	1.807	2
8	Bøggildite	3.16	M	1.767	2
9	Brazilianite	5.04	M	1.110	3
10	Cocoxenite	3.35	H	1.325	5
38a	Cheralite	3.07	M	0.963	2
11	Childrenite	2.81	O	0.777	3
12a	Clinostrengite	2.78	M	0.541	5
12	Clinovariscite	2.72	M	0.545	5
19a	Crandallite	2.92	R	2.308	5
66a	Cyrilovite	4.85	Te	2.650	5
13	Dickinsonite	3.02	M	2.462	2
11a	Eosphorite	2.82	O	0.775	3
14	Evansite	—	—	—	5
15	Faheyite	5.72	H	1.697	3
16	Fairfieldite	3.22	Tr	0.880	3
17	Fillovite	2.80	R	2.841	3
19b	Florencite	2.92?	R	2.448	5
2b	Fremontite		(Same as natromontebrasite)		
18	Frondelite	3.16	O	0.817	5
45a	Gordonite	9.6?	Tr	0.684	5
19	Goyazite	2.97	R	2.370	5
20	Graftonite	2.86, 3.50	M	0.767	2
21	Griphite	2.74	I	1.00	2
1a	Hagendorfite	2.72	M	0.868	2
19	Hamlinite		(Same as Sr goyazite)		
22	Herderite	3.11	M	1.275	3

* Including some seven phosphates (marked by an asterisk) which are known from hydrothermal deposits, but not from pegmatites.

† With $c < a < b$.

TABLE 8—(continued)

No.	Name	Strongest line Å	Crystal system	a/b^\dagger (c/a in dimetric)	Occur. (Table No.)
23	Heterosite	2.45	O	0.601	4
*	Hinsdalite	2.98?	R	2.535	3
24	Hopeite	2.85	O	0.580	5
1b	Hühnerkobelite	2.71	M	0.87?	2
25	Hureaulite	3.14	M	1.910	3
26	Hurlbutite	3.67	O	0.942	3
27	Isokite	3.18	M	0.859	3
40a	Jezebite	2.95	M	0.896	3
19b	Koivinite	2.92	R	2.346	5
*	Kolbeckite	—	M	0.838	3
28	Koninckite	—	O?	—	5
29	Kryzhanovskite	3.14, 1.85, 1.82	M	—	4
30	Lacroixite	2.91	M?	—	3
31	Landesite	3.20	(cf. reddingite)		4
45b	Laueite	9.93	Tr	0.684?	5
32	Lazulite	3.23	M	0.983	2
33	Leucophosphate	6.78	M	1.014	5
59a	Lithiophilite	2.53	O	0.580?	2
34	Lithiophosphatite	3.98	O	0.60?	3
35	Lomonosovite	—	M?	—	2
36	Ludlamite	2.55	M	2.247	3
20a	Magniophilite	2.86?	M?	0.767?	2
1c	Mangan-alluaudite	2.71?	M	0.880?	2
16a	Messelite	3.14(6.34)	Tr	0.880?	3
37a	Meta-autunite	8.40	(See metatorbernite)		
12a	Metastrengite		(See clinostrengite)		
37	Metatorbernite	3.61	Te	1.239	5
12	Metavariscite (Fe''')		(See clinovariscite)		
38	Monazite	3.05	M	0.964	2
2a	Montebrasite	2.97	Tr	0.73?	2
39	Moraesite	7.00	M	0.232	3
40	Morinite	2.95	M	0.885	3
41	Nagatelite	—	M	—	2
2b	Natromontebrasite	3.14	Tr	0.73?	2
42	Natrophilite	2.60	O	0.601	2
16a	Neomesselite		(See messelite)		
43	Palermoite	3.11	O	0.730	3
44	Parahopeite	—	Tr	0.764	5
45	Paravauxite (Mn''Fe''')	9.93?	Tr	0.684?	5
46	Parsonsite	3.22	M	—	5

TABLE 8—(continued)

No.	Name	Strongest line Å	Crystal system	$a/b†$ (c/a in dimetric)	Occur. (Table No.)
50a	Phosphoferrite	3.18	O	0.939	3
47	Phosphophyllite	2.83	M	2.065	4
48	Phosphuranylite	7.83	O	0.910	5
49	Pseudolaueite	9.93	M	1.364	4
23a	Purpurite	2.45?	O	0.601?	4
3a	Pyromorphite	2.92	H	0.735	5
50	Reddingite	3.20	O	0.941	3
48a	Renardite	7.95	O	0.915	5
18a	Rockbridgeite (Zn)	3.31	O	0.812	5
51	Roscherite	9.59	M	—	3
52	Salmonsite	9.42, 3.16, 2.85	M?	1.91?	4
53	Sarcopside	3.51	—	—	3
54	Scholzite	8.59	O	0.772	4
32b	Scorzalite	3.25	M	0.977	2
55	Sicklerite (Mn)	3.01, 2.53	O	0.587	4
55a	Sicklerite (Fe)	2.95, 2.49	O	0.589	4
56	Souzalite	2.69	M?	—	3
*	Spodiosite	2.81?	O	0.896	3
57	Stewartite	10.05	M	0.171	4
62a	Strengite	4.36	O	0.979	5
*	Svanbergite	2.98	R	2.410	3
*	Tavistockite	—	O	—	3
2c	Tavorite	3.29	Tr	0.73?	2
58	Torbernite	3.69, 10.3	Te	2.904	5
59	Triphylite	2.53	O	0.580	2
60	Triplite	2.87	M	1.862	2
61	Triploidite	2.92	M	0.916	2
62	Variscite	4.29	O	0.970	5
1d	Varulite	2.73	M	0.87?	2
63	Vashegyite	3.01, 10.5	(Same as evansite?)		5
64	Väyrynenite	3.42, 2.84	M	0.727	3
65	Vivianite	6.59	M	0.751	5
*	Wagnerite	2.95	M	0.951	3
66	Wardite	4.74	Te	2.682	5
67	Wavellite	8.40	O	0.555	5
68	Whitlockite	2.85	R	3.57	3
61a	Wolfeite	2.93	M	0.921	2
69	Xanthoxenite	—	—	—	4
70	Xenotime	3.42	Te	0.877	2
60a	Zwieselite	2.87?	M	1.864	2



FIG. 1. X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 2.45 to 2.80 Å.



FIG. 2. *X*-ray diffraction patterns for phosphates whose strongest line corresponds to d of 2.81 to 2.92 Å.

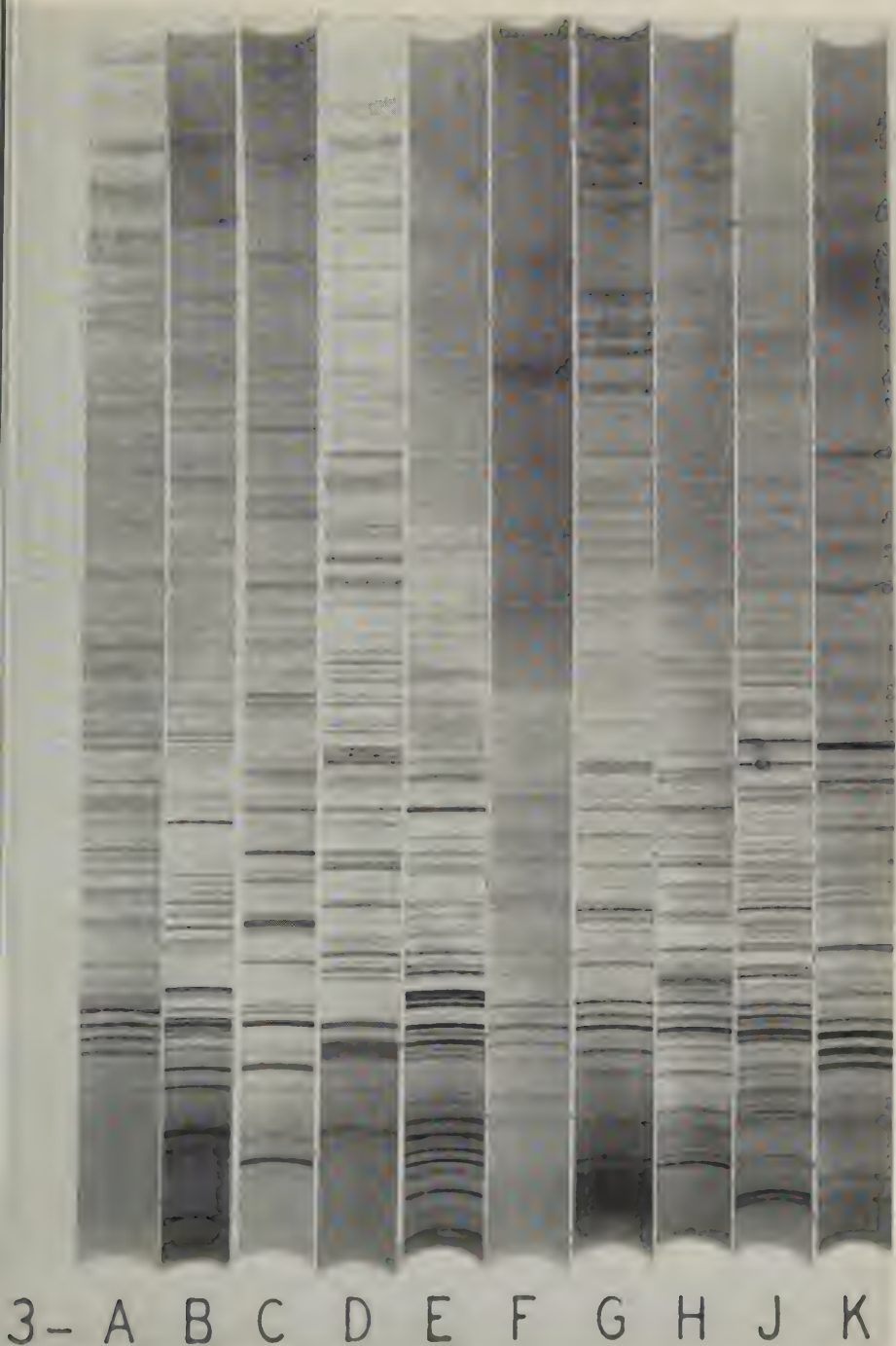


Fig. 3. X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 2.95 to 3.16 Å.



FIG. 4 X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 3.18 to 3.40 Å.



FIG. 5. X-ray diffraction patterns for phosphates whose strongest line corresponds to d of 3.4 to 6.0 Å.

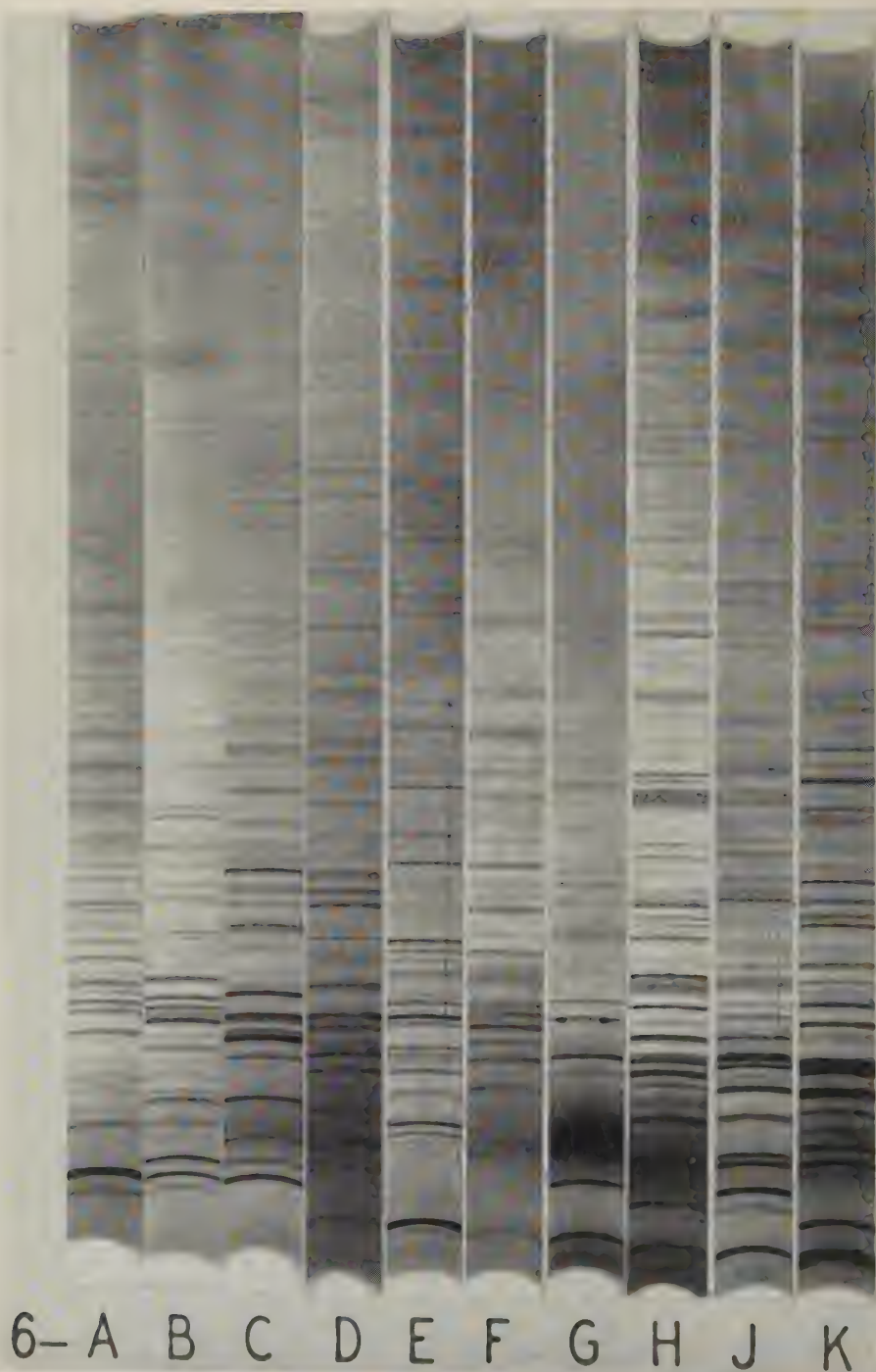


FIG. 6 X ray diffraction patterns for phosphates whose strongest line corresponds to d of 6.5 to 10.5 Å.

In Table 6 the order of listing is that of increasing a/b ratio (c/a in the dimetric) by crystal systems; for this purpose it is assumed that $c < a < b$. However the actual values of a , b , and c shown are those generally given in the literature. The next-to-the-last column in this table serves as an index to Table 7.

Table 7 lists the pegmatite phosphates in order of increasing spacing value of the most intense powder diffraction line; spacing values for the next two lines (in decreasing order of intensity) are also given. Figures 1 to 6 referred to in the fifth column (which serves as an index to these patterns) are reproductions of those films which were available in suitable quality. All photographs are approximately natural size for a 114 mm. diameter camera; all were made with iron radiation using a manganese filter; the stronger β lines generally appear. The photographs in the figures should not be used for comparing relative intensities of lines of greatly differing spacing values, since in some cases during the photographic reproduction process an effort was made to overprint zones of weak lines and suppress those of heavy lines. The last two columns of the table serve as an index to Table 6.

Table 8 constitutes an alphabetical index to Tables 2 to 7. The writer's 70 phosphates are each given a number. Thus amblygonite is no. 2; the other members of this series are shown as $2a$, montebrasite; $2b$, natromontebrasite (fremontite); and $2c$, tavorite. The third column serves as an index to Table 7, the fourth and fifth columns to Table 6, and the last column to Tables 2 to 5.

This attempt to summarize certain data dealing with the pegmatite phosphates has nothing of a definitive nature. Besides ordinary mistakes of the clerical sort, there are certainly errors of both omission and commission. In some cases it has been necessary to take a positive stand, even though the data hardly warranted this. I will be greatly pleased to be corrected, argued with, and otherwise man-handled. Should enough such material accumulate to warrant it, I will be delighted to publish it with suitable acknowledgments.

ACKNOWLEDGMENTS

The photographic reproductions of the powder films in the figures were made by W. F. Schmidt assisted by C. A. Knight. Leon Atlas helped with the x-ray work. The 33 samples used in making these 60 films that were not from the University of Chicago collections were supplied by the following. American Museum of Natural History (F. H. Pough): 1H, 2C, 3G, 4A, 5FJ. Harvard University (C. Frondel): 3D, 4CG, 5AC, 6FG. J. Kutina (Prague): 2G, 3B. H. Strunz (Berlin): 6EHJ. U. S. Geological Survey (M. L. Lindberg): 3K; (W. Schaller): 2E. U. S. National Museum (G. Switzer with the help of Mrs. Lindberg): 4FK, 5HK, 6BC. C. W. Wolfe (Boston): 1D. Yale University (H. Winchell): 1EK, 2BK, 3H, 4D.

AN ANDRADITE-SPESSARTITE GARNET FROM
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ABSTRACT

Garnet from Pajsberg, Sweden, has been found to have the following molecular per cent composition: andradite, 66; spessartite, 27; almandite, 4; grossularite, 2; and pyrope, 1. Physical properties of the analyzed mineral are: specific gravity minimum $3.96 \pm .01$, maximum $4.00 \pm .01$, average 3.98; index of refraction minimum $1.888 \pm .003$, maximum $1.898 \pm .003$, average 1.893; and unit cell size $11.99 \text{ \AA} \pm .02$. A heavier garnet fraction from the same rock has an MnO content of 14.6 per cent, equivalent to 34 molecular per cent spessartite, and physical properties for this fraction clearly indicate that most of the remaining 66 molecular per cent is andradite. The andradite-spessartite garnet occurs with rhodonite, a dark olive green mineral with the hedenbergite structure but of doubtful composition and very small amounts of chlorite, biotite, hematite, barite, and allanite, at a mine that in the past has produced both iron and manganese from an ore body located within a lens of dolomite.

GEOLOGIC OCCURRENCE

The rock specimen described here is No. 2955 of the Stanford Mineralogy Collection. It is apparently a very old acquisition and is labeled simply "Pajsberg, Sweden." According to Dr. P. Quensel of the University of Stockholm (personal communication) the Pajsberg mine is rather small, has not been worked since 1887, and is now flooded. Most of the Pajsberg samples now extant were collected prior to 1887, either by Gustav Flink or by Hj. Sjögren.

The Pajsberg mine is near Lake Yngen, about ten miles south of the famous Långban mines in Vermland, Sweden. There is little detailed information available on the geology of the Pajsberg deposit. The following description is based on the accounts of Igelström (1866), Tagengren (1924), and Quensel (personal communication). The Pajsberg mine was worked for iron ore during 1842 and 1849-1852 and for both iron and manganese ores during 1884-1887, when a total of 3,515 tons of manganese ore was produced. The iron ore is mostly hematite, with some magnetite; the manganese ore is hausmannite. Both the iron and manganese ores lie within a lens of dolomite. The manganese ore body is 6-18 feet thick and about 200 feet long; it is flanked by a larger tabular mass of iron ore. The iron and manganese ores lie in close proximity, but they are sharply divided and appear to be two separate ore bodies.

The Pajsberg ores resemble those of the nearby Långban deposits in this respect. Sjögren (1910, p. 1310) states: "It is characteristic of the Långban deposits that iron ores and manganese ores occur, on the whole, separated and independent of each other, although so close that they are mined in the same workings." The Pajsberg and Långban ores are also similar mineralogically (Tagengren, 1924, p. 22).

PETROGRAPHY

Megascopically the garnet-bearing rock is fine-grained. The fresh surface has a waxy luster and a color that is a rather uniform dark olive green tinged with brown. The hand specimen is cut by a small veinlet of rhodonite. In thin section it is seen to be composed almost entirely of rhodonite, clinopyroxene, and garnet. The grain size of the rhodonite ranges from less than 0.1 mm. to more than 1 mm. and averages about 0.2 mm. The grain size of the clinopyroxene is more uniform, most crystals being 0.1–0.3 mm. in diameter. Although rhodonite and clinopyroxene are intergrown, the pyroxene grains tend to be grouped in irregularly shaped clusters within the rhodonite. In some instances cleavage is persistent through adjacent grains of rhodonite and clinopyroxene. However, universal stage work failed to establish any symmetry between these common cleavages and the optical directions in the two minerals.

Garnet is associated with rhodonite and with clinopyroxene. Most garnet grains are less than 0.05 mm. in diameter; the largest are about 0.2 mm. Patches of a very fine-grained white opaque material are seen in one portion of the thin section, associated principally with garnet and clinopyroxene but also with rhodonite. This white material resembles leucoxene, but the presence of leucoxene here would seem to be anomalous.

Very small amounts of chlorite and biotite also are visible in thin section. The biotite is pleochroic from dark grass green (Z) to straw yellow (X).

Minor amounts of hematite (identity confirmed by means of an *x*-ray diffraction pattern) and barite and a few grains of allanite were recovered from the crushed material, but these minerals were not seen in thin section.

MINERALOGY

The optical values given below were measured in sodium light. Specific gravity values were determined in Clerici solution at room temperature by means of the suspension method.

(1) *Garnet*

The specific gravity of the garnet in this rock ranges from less than 3.85 to more than 4.11, but none of the grains has an index of refraction below 1.88. Now it is very unusual for any garnet with a specific gravity approaching or exceeding 4.0 to have an index of refraction as high as 1.88; therefore two portions of the heavier material were selected for detailed study. As the final step in the purification of these fractions, the garnet was ground to dust size and centrifuged in Clerici solution. Few of these smaller particles were zoned.

The first fraction dealt with was large enough for a complete chemical analysis. The physical properties of this garnet, determined on the material analyzed, are as follows: Specific gravity minimum $3.96 \pm .01$, maximum $4.00 \pm .01$, average 3.98; index of refraction minimum $1.888 \pm .003$, maximum $1.898 \pm .003$, average 1.893; and unit cell size $11.99 \text{ \AA} \pm .02$. In grains of 200-mesh size the mineral was dark apple green in reflected light and pale green in transmitted light. In dust-size particles,

TABLE 1. ANALYSIS OF GARNET FROM PAJSBERG, SWEDEN

(Stanford Mineralogy Collection #2955)

Eileen H. Oslund, analyst

	Weight per cent	Molecular proportions	Metals
SiO ₂	34.8	.580	2.91
Al ₂ O ₃	8.0	.078	.78
Fe ₂ O ₃	22.0	.138	1.38
TiO ₂	.06	.001	.01
MgO	.1	.003	.02
FeO	.5	.007	.04
MnO	11.4	.161	.81
CaO	22.9	.409	2.05
BaO	nil	—	—
H ₂ O (—)	.03	—	—
Total	99.8		

the color, though lighter, was still distinct apple green in reflected light and pale green in transmitted light.

The film on which the unit cell size is based was prepared by means of FeK α radiation, filtered with MnO. Lines on this film are uniformly fuzzy, making it impossible to determine the cell size more exactly than $\pm .02 \text{ \AA}$. Exposure of the mineral to CuK α radiation gave the same results. Failure of garnet of such a narrow range of specific gravity to give sharper reflections suggests a disordered structure, which in this case might be due to solid solution of large molecular per cents of andradite and spessartite.

The analysis (Table 1) gives an SiO₂:R₂O₃:RO ratio of 3.00:2.07:2.93. Assuming the Fe⁺⁺⁺ determination to be high, as is often the case in garnet analyses (Fleischer, 1937, p. 752), an adjustment to the ideal

garnet ratio of 3:2:3 is possible, and the components (molecular per cent) become: andradite, 66; spessartite, 27; almandite, 4; grossularite, 2; and pyrope, 1.

Fleischer (1937), in a statistical study of 57 garnet analyses, confirmed Ford's (1915) thesis that there is a direct relationship between chemical composition and physical properties in the garnet group.

The values used by Ford and Fleischer for the pure end members were

TABLE 2. COMPARISON OF OBSERVED AND CALCULATED PHYSICAL PROPERTIES OF PAJSBERG GARNET

	Calculated		Difference
Refractive index	Ford's value	1.862	— .031
Observed=1.893 (Avg.)	Skinner's value	1.856	— .037
Unit cell size	Fleischer's value	11.914 Å	— .076 Å
Observed=11.99 Å ± .02	Skinner's value	11.902 Å	— .088 Å
Specific gravity	Fleischer's value	3.94	— .04
Observed=3.98 (Avg.)	Skinner's value	3.96	— .02

determined by extrapolation from natural garnets of mixed composition. Skinner's (1956) values for index of refraction and unit cell size were determined from synthetic pure end member garnets, and his specific gravity figures were calculated from the volume of the unit cell.

Observed and calculated physical properties for the Pajsberg garnet are given in Table 2. The odd composition of this garnet is probably responsible for the unusually wide divergence between the observed and calculated values. Also, it is interesting to note that of the 57 garnets included in Fleischer's (1935, p. 755, analyses 56, 57) statistical study, only two minerals have the observed value for refractive index as much as .03 greater than the value calculated from the component molecules represented in the analysis. One of these is number 6 in Tables 3*A* and 3*B* of this paper. The other, also predominantly andradite, has this molecular per cent composition: andradite, 92.25; spessartite, 2.69; grossularite, 2.56, and pyrope, 2.49.

The physical properties of the second Pajsberg garnet fraction dealt with in detail are as follows: Specific gravity minimum $4.01 \pm .01$, maximum $4.11 \pm .01$, average 4.05; index of refraction minimum $1.884 \pm .003$, maximum $1.892 \pm .003$, average 1.888; and unit cell size, $11.95 \text{ Å} \pm .02$. The pure dust size material is apple green in reflected light, but as seen beside the fraction described above (specific gravity=3.96-4.00), this

heavier material has a distinct reddish hue. The color in transmitted light is pale green.

Unfortunately this fraction was too small for a complete chemical analysis, but the MnO content was determined by C. O. Ingamells of the University of Minnesota Rock Analysis Laboratory to be 14.6 per cent. This is equivalent to about 34 molecular per cent spessartite, and

TABLE 3A. ANALYSES AND PHYSICAL PROPERTIES OF GARNETS WITH HIGH MOLECULAR PER CENTS OF ANDRADITE AND SPESSARTITE

	1	2	3	4	5	6
SiO ₂	34.8	n.d.	38.63	35.24	37.57	34.34
Al ₂ O ₃	8.0	n.d.	8.20	6.48	18.98	7.20
Fe ₂ O ₃	22.0	n.d.	21.90	23.90	3.47	24.01
TiO ₂	.06	n.d.	n.d.	nil	n.d.	n.d.
MgO	.1	n.d.	n.d.	2.04	0.23	1.29
FeO	.5	n.d.	n.d.	n.d.	7.45	n.d.
MnO	11.4	14.6	13.00	16.37	16.50	5.94
CaO	22.9	n.d.	19.80	15.20	15.80	27.36
BaO	nil	n.d.	n.d.	.18	nil(?)	n.d.
H ₂ O(-)	.03	n.d.	n.d.	nil	n.d.	n.d.
Total	99.8	—	101.53	99.41	100.0	100.14
Sp. Gr.	3.98 (avg)	4.05 (avg)	n.d.	4.02	—	n.d.
R.I.	1.893 (avg)	1.888 (avg)	n.d.	n.d.	—	1.89
α_0	11.99 Å ± .02	11.95 Å ± .02	—	—	—	—

1. Garnet from Pajsberg, Sweden. Stanford Mineralogy Collection 2955. Eileen H. Oslund, analyst.
2. Garnet from Pajsberg, Sweden. Stanford Mineralogy Collection 2955. MnO determination by C. O. Ingamells.
3. Garnet from Gåsborns, Vermland, Sweden. Igelström, 1883, p. 94. L. I. Igelström, analyst. (Analysis made in 1864.)
4. "Spandite" from Garbham, India. Fermor, 1909, p. 167. J. Coggin Brown, analyst.
5. "Spandite" from Kotakarra, India. The analysis of this garnet was "calculated from analyses of rocks containing it." (Fermor, 1909, p. 168.)
6. Garnet from Franklin Furnace, New Jersey. Palache, 1936, p. 75. Jenkins and Bauer, analysts.

the physical properties determined for this fraction, together with the complete analysis listed above (specific gravity = 3.96–4.00), clearly indicate that most of the remaining 66 molecular per cent is andradite.

Earlier garnet analyses that most nearly resemble the present one are presented in Tables 3A and 3B. At first glance, number 3 of Table 3A appears to be very similar to the Pajsberg garnet (specific gravity 3.96–

4.00), but calculation shows the $\text{SiO}_2:\text{R}_2\text{O}_3:\text{RO}$ ratio to be 3.10:1.97:2.59, and the composition in terms of molecular per cents of the garnet end members is problematical. (This is not surprising, since the analysis dates from 1864.)

"Spandite" is the name proposed by Fermor (1909, p. 179) "for the varieties of manganese garnet that are intermediate, as regards composi-

TABLE 3B. COMPONENTS (MOLECULAR PER CENTS) OF GARNETS
LISTED IN TABLE 3A

Analysis Number (As in Table 3A)	Components (Molecular per cents)						Totals
	Andra- dite	Spessar- tite	Alm an- dite	Grossu- larite	Pyrope	$\text{Mn}_3\text{Fe}_2\text{Si}_3\text{O}_{12}$ ("Calderite")	
1	66	27	4	2	1	—	100
2	—	34	—	—	—	—	—
3	PROBLEMATICAL						—
4	47	19	6	0	8	20	100
5	10	38	16	35	1	—	100
6	68	14	0	13	5	—	100

1. Pajsberg, Sweden. Specific gravity=3.96-4.00.
2. Pajsberg, Sweden. Specific gravity=4.01-4.11.
3. Gåborns, Vermland, Sweden.
4. Garbham, India.
5. Kotakarra, India (analysis "calculated").
6. Franklin Furnace, New Jersey.

tion, between spessartite and andradite." Number 4 of Tables 3A and 3B is the only actual analysis of spandite presented by Fermor; number 5 was "calculated from the analyses of rocks containing it" (Fermor, 1909, p. 168). Of the naturally occurring garnets known to the writer, number 6 of Tables 3A and 3B, from Franklin Furnace, New Jersey, most nearly resembles the Pajsberg garnet. Despite similarity in chemical composition, however, the Franklin Furnace mineral is brownish black (Palache, 1936, p. 75), in contrast to the apple green color of the Pajsberg garnet.

(2) *Clinopyroxene*

This mineral has the hedenbergite structure, for the powder diffraction pattern corresponds to that of an analyzed johannsenite, with slight differences in spacing resulting from compositional differences.

The physical properties are: $\alpha = 1.727$, $\beta = 1.740$, $\gamma = 1.756$, all $\pm .004$; $\gamma - \alpha = .029$ and dispersion $v > r$, moderate. Most crystals have a specific gravity within the range 3.45–3.49, but a few are outside these limits. Universal stage plots of five grains (with one axis observed in every case) gave these values for 2V: 72(+), 84(+), 88(+), 86(–), and 82(–). For $X \wedge c$ grains 2–5, respectively gave 22°, 23°, 19°, and 18°. At a grain size within the range 0.07–0.15 mm., the pure mineral has a very dark olive green color in reflected light. In thin section the color is greenish yellow. Pleochroism is slight, from greenish yellow to a more definite yellowish hue, with $X > Y > Z$.

Flink (1886, p. 496) gives the following analysis for a dark iron schefferite from Pajsberg: SiO_2 , 50.88; Al_2O_3 , 1.97; FeO , 17.48; MgO , 9.08; MnO , 6.67; CaO , 12.72 and total, 98.81. This iron schefferite occurs with rhodonite, hematite, and barite and has a yellow-green color in thin section (Flink, 1886, p. 500), which suggests that it might have a composition similar to that of the clinopyroxene described above. Unfortunately, neither refractive index nor 2V values are listed for Flink's analyzed iron schefferite.

One might expect a clinopyroxene paragenetically associated with andradite-spessartite garnet and rhodonite to have the composition of a manganhedenbergite or an iron schefferite. The refractive indices and specific gravity of this mineral favor the former alternative (see for example Tilley, 1946, p. 237; Palache, 1936, p. 62). However, the combination of physical properties displayed by this clinopyroxene, including particularly the values for 2V and $X \wedge c$, leave the composition of the mineral in doubt (see Winchell, 1951, pp. 411–417).

(3) *Rhodonite*

The identity of this mineral was checked by means of an x-ray diffraction pattern. Physical properties are: specific gravity maximum 3.64, minimum 3.61, both $\pm .01$; $\alpha = 1.724$, $\beta = 1.730$, $\gamma = 1.738$, all $\pm .004$; $\gamma - \alpha = .014$, and dispersion $r < v$, very slight. Universal stage plots of four grains gave these results for 2V, (+) in every case: 70, 72, 73 and 84. Both optic axes were observed for grain 2, only one for each of the others.

Specific gravity and index of refraction (β) values determined for this rhodonite suggest that the composition includes 85–90 molecular per cent of $\text{MnSiO}_3 + \text{FeSiO}_3$ (Hey, 1929, pp. 201–202; Lee, 1955, pp. 21–23). Moreover, the color of the pure mineral, which is a dull pink in grains of 200-mesh size, indicates that the FeO content is relatively high, for iron-poor rhodonites commonly have a bright peach-pink color (Lee, 1955, pp. 19–21).

CONCLUSION

Despite limited miscibility of the grossularite-andradite with the pyrope-almandite-spessartite series of garnets, Boeke (1913, p. 155) has predicted (empirically) that the andradite end member has a special capacity to contain MnO. Results of this study show that under proper conditions of formation natural andradite may contain more than 27, and probably as much as 34, molecular per cent spessartite.

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REFERENCES

1. BOEKE, H. E. (1913), "Die Granatgruppe": *Z. Krist.*, **53**, 149-157.
2. FERMOR, L. LEIGH (1909), "The Manganese Ore Deposits of India": *Mem. Geol. Surv. India*, **37**, 610 pp., esp. pp. 161-186.
3. FLEISCHER, M. (1937), "The relation between chemical and physical properties in the garnet group": *Am. Mineral.*, **22**, 751-759.
4. FLINK, G. (1886), "Studien über schwedische Pyroxmineralien": *Z. Krist.*, **11**, 449-530, esp. pp. 495-501.
5. HEY, M. H. (1929), "The variation of optical properties with chemical composition in the rhodonite-bustamite series": *Mineral. Mag.*, **22**, 193-205.
6. IGELSTRÖM, L. I. (1866), "Über das Vorkommen von gediegenem Blei in den Eisen- und Manganerz-Lagerstätten von Pajsberg in Schweden": *N. J. für Min., Geol. u. Paleon.*, p. 225.
7. IGELSTRÖM, L. I. (1883), "Manganmineralier från Stålmalmgrufvorna i Gåsborns socken, Vermland": *Översigt af Kongliga Vetenskaps-Akademiens Fordhandlingar, Stockholm*, **40**, No. 7, 91-96. (Trans. by Gail Keith Meadows)
8. LEE, DONALD E. (1955), "Mineralogy of some Japanese manganese ores": *Stanford Univ. Publ., Univ. Ser., Geol. Sci.*, **5**, 64 pp., esp. pp. 19-23.
9. PALACHE, CHARLES (1936), "The Minerals of Franklin and Sterling Hill, New Jersey": *U.S.G.S. Prof. Paper 180*, 130 pp., esp. pp. 62, 75.
10. SJÖGREN, H. (1910), "The Långban Mines": *Geol. Förh. Förh., Stockholm*, **32**, pp. 1295-1325, esp. pp. 1310-1313.
11. SKINNER, BRIAN J. (1956), "Physical properties of the garnet group": *Am. Mineral.*, **41**, 428-436.
12. TAGENGREN, F. R. (1924), "Sveriges Äldre Malmer och Bergverk": *Sveriges Geologiska Undersökning*, Ser. Ca. No. **17**, pp. 1-406, esp. pp. 21, 22, 211, 212, which were translated by Gail Keith Meadows.
13. TILLEY, C. E. (1946), "Bustamite from Treburland Manganese Mine, Cornwall, and its Paragenesis": *Mineral. Mag.*, **27**, 236-241.
14. WINCHELL, ALEXANDER N. (1951), *Elements of Optical Mineralogy, Part II, Descriptions of Minerals*, pp. 411-417, John Wiley & Sons.

Mg-VERMICULITE: A REFINEMENT AND RE-EXAMINATION OF THE CRYSTAL STRUCTURE OF THE 14.36 Å PHASE

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ABSTRACT

Refinement of the crystal structure of the 14.36 Å phase of Mg-vermiculite by difference syntheses does not change the earlier general conclusions regarding the silicate layer, but reveals an electron density distribution in the interlamellar region which indicates either that the water molecules are vibrating asymmetrically or that there is a regular displacement of water sites from the hexagonal position in a direction opposite to that proposed in the earlier analysis by Mathieson and Walker. The present evidence is not decisive but tends to support the latter alternative. Additional supporting evidence is provided by a careful comparison of the structures of Mg-vermiculite and chlorite.

INTRODUCTION

The crystal structure of Mg-vermiculite at normal temperature and humidity (Mathieson and Walker, 1954) was analysed by means of orthodox ρ_0 syntheses. It has become evident recently (e.g., Cochran, 1951; Cruickshank, 1956) that in ρ_0 syntheses much detail concerning minor atomic displacements and vibrations remains hidden and can best be revealed by the use of difference syntheses (Cochran, 1951). It was considered worthwhile to attempt a refinement of the available diffraction data for this phase of Mg-vermiculite by means of $\Delta\rho$ syntheses. The additional information will be of interest with respect to triphormic layer silicates in general (for reasons, see Walker, 1957) and the improved data will assist in a current investigation of the various phases of Mg-vermiculite (Walker, 1956). It is convenient to distinguish the various phases by means of their basal spacing. Hence we shall refer to normal Mg-vermiculite as the 14.36 Å phase.

REFINEMENT

No new diffraction measurements were made; the data used were the experimental $h0l$ structure amplitudes recorded in Table 2 of the original analysis (Mathieson and Walker, 1954, hereafter referred to as I). The first difference synthesis was calculated using the recorded F_{obs} and F_{calc} values (Fig. 1a). From inspection of this distribution, it was clear that various parameter adjustments were required, in particular for D, O_3 and O_{2AB} (see Table 1 and Fig. 1c), while the region of the water molecule sites showed a gross error in the temperature factor (for which an average value, $B=1.2 \text{ \AA}^2$, was used in I) with a negative trough of

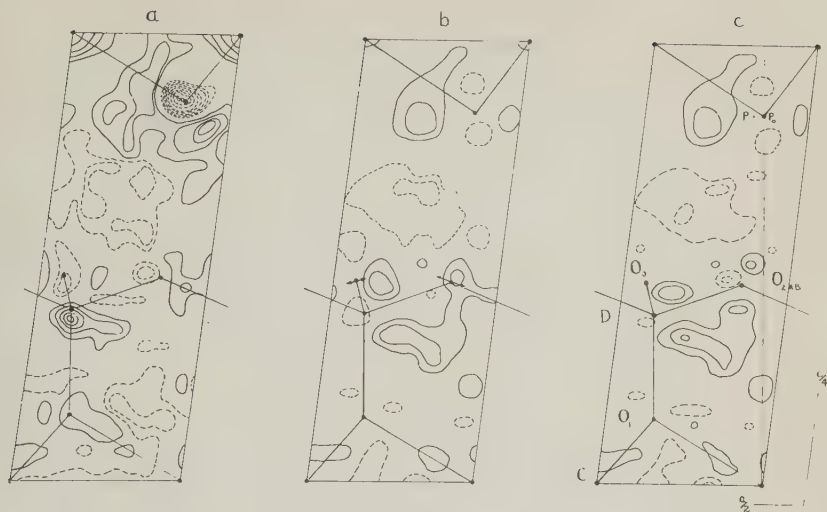


FIG. 1. Difference Fourier syntheses: *a*) first, *b*) eleventh and *c*) thirteenth. The contour levels are at intervals of $1e.\text{\AA}^{-2}$, the full line representing positive, dashed line negative values, the zero level being omitted. The molecular model is outlined, the vibration directions of O_3 and O_{2AB} being indicated in *b*).

$9e.\text{\AA}^{-2}$ where the peak value in the distribution was only $\approx 22e.\text{\AA}^{-2}$. In subsequent calculations of structure amplitudes, improved scattering curves for O^{-2} , Si^{4+} , Al^{3+} and Mg^{2+} (MacGillavry *et al.*, 1955), tabulated since the previous analysis, were used and the three water sites we assumed to coincide in projection, leaving the question of site displacement until other features of the electron density distribution had been clarified. Adjustment of atomic parameters and isotropic temperature factors was made step by step by the iterative process of calculation of structure amplitudes, adjustment of $\sum |F_{obs}| = \sum |F_{calc}|$ and subsequent synthesis. After the eleventh $\Delta\rho$ synthesis (Fig. 1*b*) all mean atomic parameters and mean isotropic temperature factors had been determined (Table 1). In the region of O_3 , a classical type of $\Delta\rho$ distribution (Cochran and Lipson, 1953, p. 304) indicated asymmetric vibration. A similar distribution occurs around O_{2AB} , but here the mean value of B (2.0\AA^2) used for O_3 and O_{2AB} in the calculation of structure amplitudes was too high, so that in addition a positive region existed at the atom centre. The vibration directions (Fig. 1*b*) indicated by these distributions were in accord with the bonding of O_3 , O_{2A} and O_{2B} with D atoms. In three dimensions, these three oxygen atoms are structurally equivalent (Fig. 2*c*) but in the *b*-axis projection, the range of vibration of O_3 is viewed at its maximum while the superimposed vibrations of

TABLE 1. ATOMIC PARAMETERS AND TEMPERATURE FACTORS

Approximate peak value in (e. Å ⁻²)	Atom	x/a	z/c	B (Å ²)	
				11th $\Delta\rho$	13th $\Delta\rho$
21	Mg ²⁺	0.50	0.250	1.2	1.2
22	H ₂ O	0.1403	0.2104	5.4	5.4
20	O ₃	0.4322	0.1142	2.0	$0.8s^2+2.4t^2$
40	O _{2AB}	0.1482	0.1142	2.0	$0.8s^2+1.2t^2$
99	D(SiAl)	0.3967	0.0951	0.8	0.8
63	O ₁	0.3579	0.0369	1.4	1.4
136	C(Mg, Fe, Al)	0.0	0.0	1.2	1.2

s and t are defined in Cochran (1951).

O_{2A} and O_{2B} are both viewed at 30°. Hence the apparent range of vibration for O_{2AB} is smaller (i.e., smaller mean B) and the direction of vibration is different (vide Fig. 1b). The asymmetric vibrations of O₃ and O_{2AB} were then removed from the $\Delta\rho$ distribution by calculating the contributions of these oxygen atoms with the appropriate asymmetric temperature factors (Table 1) using Cochran's (1951) method. The resulting distribution is shown in Fig. 1c. Whereas in I, the final reliability index ($R = \sum |F_0 - F_c| / \sum |F_0|$) was 0.17, the index has now been reduced to 0.08. The final observed and calculated structure amplitudes are compared in Table 2.

At this stage there remained in the region of the silicate layer (i.e., $z=0$ to $c/8$) no systematic features which could be related to any error, either in the parameters or asymmetric vibrations of any of the atoms. The distribution remaining must correspond therefore to random variations arising from errors in the measurement of structure amplitudes. On this basis, it is possible, since gross features in the region $z=c/8$ to $c/4$ have also been removed, to use the region $z=0$ to $c/8$ in the 13th $\Delta\rho$ distribution (Fig. 1c) to estimate the standard deviations in $\Delta\rho$ and in the slope of $\Delta\rho$. These have been calculated from the relationships, $\sigma(\rho) = |\Delta\rho|^2$ ^{1/2} and $\sigma(\partial\Delta\rho/\partial z) = \{(\partial\Delta\rho/\partial z)^2\}$ ^{1/2} (Cochran and Lipson, 1953). Averaged over 232* points, the standard deviation of electron density $\sigma(\rho) = 1.0\text{e.}\text{\AA}^{-2}$ while, averaging the (slope)² over 239 points, the standard deviation $\sigma(\partial\Delta\rho/\partial z) = 4.56\text{e.}\text{\AA}^{-3}$. With this latter value, the standard deviations for atomic parameters, $\sigma(z_n) = \partial\Delta\rho/\partial z/C_n$, can be computed when the central curvature at each atom peak, C_n , in ρ_0 has been determined. C_n may be conveniently assessed as $2p\rho_0$, p being determined from a plot of $\log \rho_0$ against r^2 (see Cochran and Lipson, 1953, p. 279, 308). The calculated values of standard deviations are listed in Table 3

* Subdivision of the unit cell axes in computing the Fourier series was as in I.

TABLE 2. COMPARISON OF OBSERVED AND FINAL CALCULATED VALUES OF h0l
STRUCTURE AMPLITUDES OF 14.36 Å Mg-VERMICULITE AT ROOM TEMPERATURE

l	F _o	F _c	l	F _o	F _c	l	F _o	F _c
	00l		24	105	115	40	<23	10
			22	79	85	38	46	48
2	282	273	20	37	-42	36	63	66
4	62	47	18	63	-69	34	35	14
6	110	-68	16	37	32	32	<20	-22
8	211	212	14	173	185	30	<20	-22
10	342	305	12	263	259	28	<19	25
12	60	-52	10	105	101	26	52	52
14	105	-114	8	178	182	24	52	52
16	74	-79	6	116	90	22	29	24
18	86	95	4	304	316	20	29	26
20	167	172	2	205	204	18	46	40
22	84	95	0	136	139	16	150	142
24	121	114	2	16	6	14	162	154
26	42	50	4	147	-161	12	144	141
28	83	84	6	32	20	10	<16	-16
30	68	76	8	100	83	8	16	-22
32	107	109	10	147	164	6	63	64
34	61	69	12	58	63	4	167	151
36	<20	-2	14	47	-55	2	58	77
38	38	-44	16	152	144	0	110	-112
40	<22	2	18	236	218	2	87	-84
42	41	52	20	294	283	4	127	122
44	39	50	22	63	67	6	225	224
46	<24	-11	24	<16	-15	8	167	181
48	<24	-23	26	16	14	10	<16	-17
50	<25	17	28	105	110	12	58	58
52	54	63	30	89	98	14	127	132
54	39	42	32	<17	2	16	196	202
			34	52	-58	18	75	86
			36	<18	-9	20	<18	-8
			38	37	51	22	29	-28
52	<22	8	40	73	75	24	<18	15
50	<22	-18	42	37	31	26	52	48
48	<21	-13	44	26	13	28	58	52
46	<20	13	46	<20	12	30	17	25
44	37	46	48	47	38	32	<20	12
42	32	32	50	47	41	34	<20	3
40	<19	2	52	37	30	36	63	53
38	<18	-6				38	81	78
36	68	66		40l		40	81	70
34	100	110				42	<22	8
32	105	107	48	29	34	44	<22	-14
30	<16	0	46	46	50	46	<23	10
28	16	-21	44	23	26	48	40	46
26	16	26	42	<24	-10			

TABLE 2—(continued)

l	F ₀	F _c	l	F ₀	F _c	l	F ₀	F _c
	60l		20	50	—55	12	48	54
			22	<19	—4	14	<20	22
36	<22	18	24	86	90	16	<20	—6
34	<21	—21	26	81	85	18	<21	—6
32	<20	—20	28	30	32	20	37	39
30	20	22	30	<20	—15	22	63	56
28	76	72	32	30	30	24	58	53
26	50	56	34	60	68		10.0l	
24	<19	16	36	55	63			
22	<19	—6		80l		14	<26	13
20	50	50				12	47	37
18	81	80	24	<24	—3	10	26	32
16	66	69	22	<24	5	8	<25	14
14	<18	—6	20	<23	27	6	<24	—4
12	35	—33	18	<23	21	4	<24	4
10	<17	—5	16	<22	1	2	<23	15
8	45	51	14	<22	—22	0	<23	22
6	60	64	12	<22	—1	2	<23	5
4	35	38	10	42	38	4	<22	—9
2	<17	—1	8	79	70	6	<22	—12
0	35	32	6	37	38	8	<22	13
2	71	72	4	<21	5	10	36	33
4	141	142	2	<21	1	12	42	34
6	96	96	0	63	57	14	<23	9
8	35	40	2	74	72	16	<23	0
10	20	—22	4	32	35	18	<24	16
12	<18	24	6	26	—30	20	36	39
14	76	80	8	20	—28	22	26	30
16	66	70	10	<20	18			
18	<19	—15						

TABLE 3. (a) STANDARD DEVIATIONS OF ATOMIC PARAMETERS. (b) BOND LENGTHS

(a)		(b)	
Atom	$\sigma(z) = \sigma(x)$		
H ₂ O	0.027 Å	C—O ₁	2.071 ± 0.006 Å
O _{2AB}	0.010 Å	O ₁ —D	1.67 ± 0.01 Å
O ₃	0.019 Å	D—O ₃ =D—O _{2A} =D—O _{2B}	1.63 ± 0.02 Å
D	0.003 Å	Mg ²⁺ —H ₂ O	2.11 ± 0.03 Å
		(hexagonal site)	
O ₁	0.006 Å	O ₃ (or O _{2A} or O _{2B})—H ₂ O	2.87 ± 0.04 Å
		(hexagonal site)	

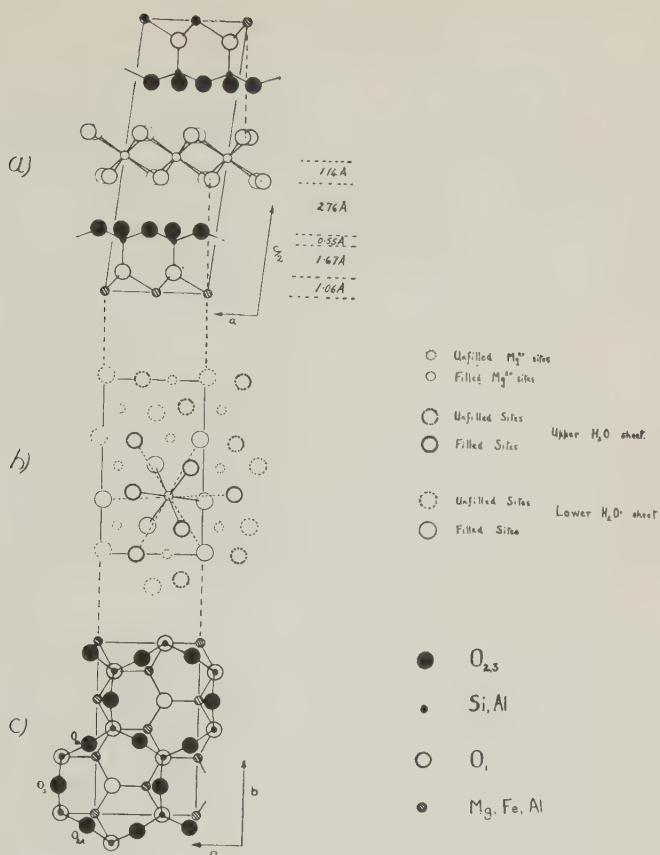


FIG. 2. The crystal structure of Mg-vermiculite involving displacement of water molecules from the hexagonal sites.

a) projection on the ac plane

b) projection of the interlamellar region normal to the ab plane

c) projection of the triphormic silicate layer from $z=0$ to $c/8$, normal to the ab plane.

The various atom species are designated on the right.

together with the bond lengths and their probable errors derived from the standard deviations. Standard deviations for O_3 and O_{2AB} were calculated on the basis of an isotropic temperature factor since, for these atoms, the direction of maximum vibration does not greatly affect the calculation of associated bond lengths.

Comparison of bond lengths (Table 3) in the silicate layer with values reported in I shows no significant change. The bond length $D-O_1$ remains greater than $D-O_{2AB}$ (O_3). The surface oxygens O_3 , O_{2A} and O_{2B} still deviate from a regular hexagon formation (Fig. 2c) and are now

observed to vibrate asymmetrically. The parameter changes all lie within the range of error quoted in I, but it is now possible to give a better estimate of the individual errors.

There appear to be changes of significance with regard to the detailed structure of the inter-lamellar region. The z parameter of the H_2O peak is considerably altered, so that whereas the inter-sheet distance $\text{Mg}-\text{H}_2\text{O}$ was previously regarded as the same as the $\text{Mg}-\text{O}$ intersheet distance (i.e., 1.06 \AA), it has now been increased to 1.14 \AA (Fig. 2a). The asymmetric electron-density distribution around the H_2O site warrants a more detailed discussion.

THE INTERLAMELLAR REGION

When the normal criteria for the correct location and mean temperature factor of a single atom have been achieved, namely $\Delta\rho=0$ and $\partial\Delta\rho/\partial z = \partial\Delta\rho/\partial x = 0$ at the atom centre, there still remains a distribution of electron density around the site of the water molecules (Fig. 1c). Since the peak values of the distribution lie in the range -1.7 to $+2.4e.\text{\AA}^{-2}$ and the standard deviation of electron density has been estimated as $1e.\text{\AA}^{-2}$, it appears that the regular shape of the distribution does not arise from random errors but from the disposition of the water molecules.

So far it has been assumed in calculating the contribution of the water molecules to structure amplitudes that the three equivalent H_2O sites coincide in the b -axis projection. On this assumption, the only conclusion regarding the asymmetric distribution is that it must be ascribed to asymmetric vibrations of the three superimposed water molecules with the major vibration mode parallel to (001) (Cochran and Lipson, 1953, p. 304). If this viewpoint is correct then all H_2O sites are structurally as well as crystallographically equivalent, all $\text{Mg}-\text{H}_2\text{O}$ interatomic distances would be 2.11 \AA and the particular grouping of the Mg^{2+} ions and the H_2O molecules over the hexagonal arrays of their respective sites would depend on the tendency of the Mg^{2+} ions to form hydration shells of the type shown in Fig. 3a(ii) (see also Fig. 7 in I).

The coincidence of the H_2O sites in the b -axis projection is not however a structural or a crystallographic necessity, but merely the simplest assumption used in the preliminary stages of the re-examination. Considering the equivalence of the [010], [310] and $[\bar{3}10]$ projections (see I), it is clear that the water molecules may be displaced in a regular manner from the hexagonal sites (Fig. 4a and b). In projection, one site is displaced Δ while the other two sites are displaced in the opposite direction by $\Delta/2$, the weighted mean being at the hexagonal site, Fig. 4(iii).

It is worth considering what effect these displacements would have on

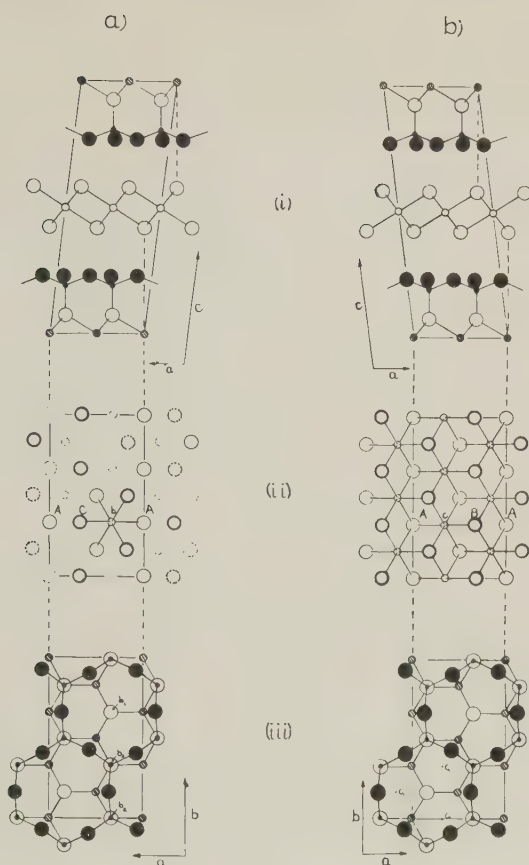


FIG. 3. Comparison of the crystal structures of *a*) Mg-vermiculite (with H_2O in hexagonal sites) and *b*) chlorite. The origin and orientation of the silicate layers is the same in both. Atom species and their levels are in Fig. 2.

- (i) projection on the ac plane
- (ii) projection of the interlamellar region normal to the ab plane
- (iii) projection of half the silicate layer normal to the ab plane.

the distribution in a difference synthesis. Consider a simple one-dimensional case where three atoms are located at $x=0$ (Fig. 5*a*). The electron density distribution for an atom can be described by a Gaussian curve (Booth, 1946). If one atom is displaced $+\Delta$ and the other two $-\Delta/2$, the resulting electron density distribution is as given in Fig. 5*b*. The $\Delta\rho$ distribution corresponding to $\rho_2-\rho_1$ is shown in Fig. 5*c*. Although intuitively the positive excursions of $\Delta\rho$ on either side of $x=0$ might have been expected to differ in magnitude, any difference is undetectable. The mean

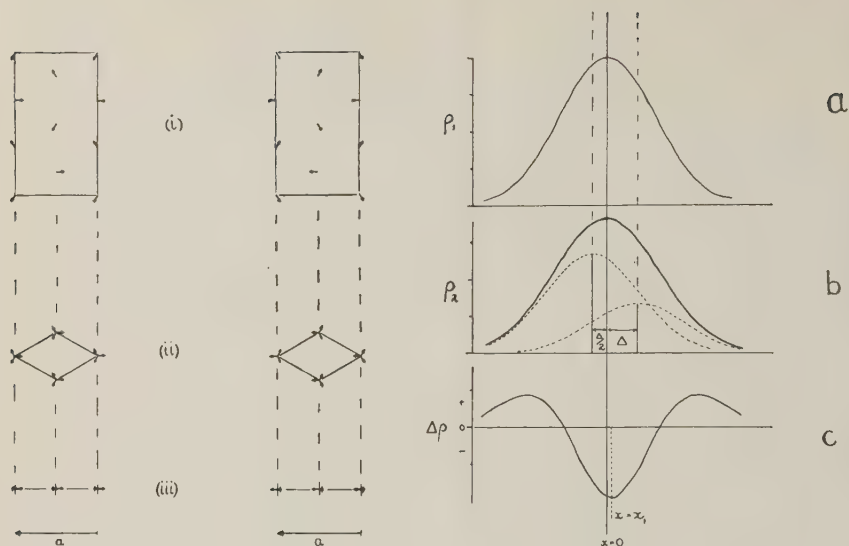


FIG. 4. (left)—The two ways in which regular displacements of the H_2O sites from the hexagonal positions in one sheet may occur.

- (i) projection on the ab plane of the full unit cell
- (ii) projection on the ab plane of the sub-cell
- (iii) projection on the ac plane.

FIG. 5. (right) Theoretical electron density distribution

- a) for three atoms superimposed at $x=0$
- b) for two atoms displaced to $+\Delta/2$ plus one atom displaced to $-\Delta$. Separate curves dashed, combined curve full line.
- c) The difference curve corresponding to $\rho_2 - \rho_1$ apparently centred at $x = x_1$.

position of the distribution is not at $x=0$ but is displaced to $x=x_1$. Hence, without prior knowledge, this distribution, Fig. 5c, could not be distinguished from the distribution of atoms superimposed at $x=x_1$ and with a major vibration mode parallel to x .

In Fig. 1c, the mean position of the asymmetric distribution is in the region of P. However, from the equivalence of the $[010]$, $[310]$ and $[3\bar{1}0]$ projections, the location of the mean position must be at P_0 (i.e., vertically above the origin Mg atoms). If this difference PP_0 is regarded as significant, the simple assumption that the water molecules superimpose at P_0 must be abandoned. The H_2O sites must be considered as displaced in three-dimensional space from the hexagonal sites by an amount Δ , i.e., by displacements of the type shown in Fig. 4b. No attempt to calculate further sets of structure amplitudes on this basis has been made since

the results would not have been sufficiently critical to yield a specific value of Δ .

If this evidence regarding H_2O sites being displaced from the hexagonal sites is correct, the refinement with difference syntheses has, therefore, led to the same type of structure in the interlamellar region as was suggested in I, except that the direction of displacement of the water molecules is reversed, i.e., as in Fig. 4*b* rather than Fig. 4*a* (cf. Fig. 6 in I with Fig. 2*b*). The structure with these displacements is shown in Fig. 2, the filling of available sites being based on the same premises as presented in I.

It must be realised that the present diffraction data are not sufficiently accurate to make a decisive choice between the two possible interpretations (1) that the water molecules lie in the regular hexagonal array of sites and are vibrating with their major mode in the (001) plane or (2) that the water molecules are in sites displaced by an amount Δ (probably of the order of 0.2 \AA) from the hexagonal sites. The most satisfactory test as to which alternative is correct would be a structure study at low temperatures (circa 80° K.) which would differentiate the effect of asymmetric vibration at room temperature from that of displacements.

Certain evidence of a less direct nature may be offered in support of the second possibility. The mean temperature factors of the atoms in Mg-vermiculite at room temperature all have normal moderate values with the exception of the H_2O molecules, 5.4 \AA^2 , despite the fact that the temperature factor of the exchangeable Mg^{2+} remains small although sandwiched between the two sheets of water molecules. The large value of B quoted for the water molecules is associated with calculations of structure amplitudes in which the three H_2O sites are assumed superimposed. If the atoms are displaced, then values of B for individual water molecules would be smaller (say 2.5 \AA^2) and more in line with values for other atoms, although B for the group (regarded effectively as one atom) would remain as 5.4 \AA^2 . This can be seen more readily by inspection of Fig. 5. The value of B is the same for individual atoms in Fig. 5*b* (dashed curves) as for the superimposed atoms in Fig. 5*a*, but the effective B for the group of displaced atoms regarded as a single entity (full curve in Fig. 5*b*) would be much larger. Hence the experimental values of the temperature factors B tend to support the view that the water molecules are displaced and not merely vibrating.

Because Mg-vermiculite resembles chlorite (Brindley, 1951) structurally in many respects, but differs from it mainly in the reduced population of the atom species in the interlamellar region, a close comparison of the two structures throws some light upon the detailed structure of the inter-

lamellar region of vermiculite. Both minerals have similar cell dimensions and have as their major constituent and principal common feature, the triphormic silicate layer. To emphasise the basic similarities and differences, the structures are shown in Fig. 3 with the silicate layers disposed in the same orientation in both and the origins of each unit cell selected as the Mg atoms at the centre of the silicate layer. The water molecules in Mg-vermiculite are shown provisionally in the hexagonal sites, i.e., undisplaced. Comparison of Fig. 3(i) (*a* and *b*) immediately shows that the disposition of the $\text{H}_2\text{O}-\text{Mg}^{2+}$ H_2O double sheet in vermiculite, although structurally similar to the $\text{HO}-\text{Mg}^{2+}$ HO double sheet in chlorite, is oriented in the opposite sense.* However, we note that in both minerals, the relationship of each sheet of H_2O (or OH) sites to the adjacent related silicate layer is the same, i.e., the oxygens lie vertically over the origin Mg atoms in a hexagonal array (Fig. 3(i)(*a* and *b*)). From this viewpoint, the main difference between Mg-vermiculite and chlorite lies in the way the two silicate- H_2O (OH) halves of the sandwich are held together by the Mg^{2+} ions. There are two possible ways of close-packing the two oxygen (H_2O or OH) sheets (capital letters) with the intercalated sheet of Mg^{2+} ions (small letter) — namely AbC or AcB, Fig. 3(ii)(*a* and *b*). In chlorite, all Mg sites are occupied and so must be structurally equivalent. Both sets of *b* and *c* sites available for Mg^{2+} ions are equivalent with respect to the hexagonal array of OH groups. Whereas *c* sites are also equivalent with respect to the underlying silicate layer, the *b* sites are of two types, namely, b_1 (over the centre of the hexagon of surface oxygens) and b_2 (over the centre of triads of surface oxygens) (Fig. 3(iii)(*a* and *b*)). Complete structural equivalence is achieved in chlorite by the location of the Mg^{2+} ions in the $c_1c_1c_1$ sites. In Mg-vermiculite, if the H_2O sites are in a regular array, the Mg^{2+} ions might be expected to occupy sites $c_1c_1c_1$, but, *because they are influenced directly or indirectly by the structure of the adjacent silicate layers*, they occupy the alternative sites $b_1b_2b_2$. Since there is not a sufficiently high population of Mg^{2+} ions to fill all sites (in contrast to chlorite), the influence of the silicate layer leads them to select either b_1 or b_2 sites. We have previously deduced from the intensity distribution of the diffuse 02l spectra of Mg-vermiculite that the Mg^{2+} ions occupy only b_2 sites (see I for details). Since the H_2O sites are approximately two-thirds occupied, the water molecules tend to congregate around the Mg^{2+} ions, but, because they are not hedged around by other water molecules in the plane of the H_2O sheet (as are the hydroxyl groups in the brucite layer in chlorite), the forces acting be-

* The implications of this difference between Mg-vermiculite and chlorite may not have been fully appreciated in discussions of chlorite-vermiculite mixed crystals.

tween surface oxygen atoms and water molecules tend to displace them from the special hexagonal sites. (To visualise this, imagine Fig. 3*a(ii)* and *(iii)* superimposed). The resultant repulsive forces* tend to rotate the H₂O triads and it is suggested that the final result is as shown in Fig. 2*b*. Alternatively, we may consider that the silicate layer influences the configuration of the H₂O sheet (only partly occupied) producing a distorted network which permits Mg²⁺ ions to occupy only *b*₂ sites. This was the viewpoint presented in I (section 4). The existence of these differences between Mg-vermiculite and chlorite provides some further indirect support for preferring the second alternative, namely, that the water molecules are displaced from the hexagonal sites.

Although incidental to this study, it is of interest that the refinement by $\Delta\rho$ syntheses has revealed the reason for the small dimensional difference in *d*(001) spacing of Mg-vermiculite (14.36 Å) and chlorite (14.2 Å) (Brindley, 1951). The H₂O—Mg—H₂O intersheet distance in vermiculite is $2 \times 1.14 \text{ Å} = 2.28 \text{ Å}$ (Fig. 2*(a)*), while HO—Mg—OH is $2 \times 1.06 \text{ Å} = 2.12 \text{ Å}$, a difference of $0.16 \text{ Å} = 14.36 - 14.2 \text{ Å}$. It would appear, therefore, that the vertical distance between each surface oxygen and its associated H₂O (or OH), 2.76 Å, is the same in both structures, further stressing the essential similarity of the H₂O(OH)—silicate—H₂O(OH) unit and the important differentiation effected by the influence of cation and water molecule (hydroxyl group) population.

REFERENCES

- BOOTH, A. D., *Proc. Roy. Soc.*, **A188**, 77 (1946).
 BRINDLEY, G. W., *X-Ray Identification and Crystal Structures of Clay Minerals*. edit. G. W. Brindley, Min. Soc., London. Chap. VI (1951).
 COCHRAN, W., *Acta Cryst.*, **4**, 81 (1951).
 CRUICKSHANK, D. W. J., *Acta Cryst.*, **9**, 915 (1956).
 LIPSON, M. AND COCHRAN, W., *The Determination of Crystal Structures*, G. Bell, London (1953).
 MACGILLAVRY, D. H. *et al.*, *Acta Cryst.*, **8**, 478 (1955).
 MATHIESON, A. McL. AND WALKER, G. F., *Am. Mineral.*, **29**, 231 (1954).
 WALKER, G. F., *Proc. Fourth National Conference on Clays and Clay Minerals*, 101 (1956).
 WALKER, G. F., *Clay Min. Bull.*—in press.

Manuscript received July 7, 1957

* A similar long-range torque was invoked in I to explain the observed rotation of surface oxygen triads. In that case, the force between Mg²⁺ and O^{δ-} was attractive while here since the force is acting between O^{δ-} and H₂O^{δ-}, both of negative charge, it is repulsive and operates in the opposite sense.

CRYSTAL AND TWIN STRUCTURE OF DIGENITE,¹ Cu₉S₅

GABRIELLE DONNAY,* J. D. H. DONNAY,† AND G. KULLERUD*

ABSTRACT

Digenite undergoes a rapidly reversible and non-quenchable transformation between 60 and 65° C. Digenite was synthesized in octahedra modified by small cube faces. Single-crystal methods yield a cubic cell whose edge a is equal to five times the literature value: $a = 27.71 \text{ \AA} \pm 0.3\%$. With 100 Cu₉S₅ per cell, the calculated specific gravity is 5.715, against 5.6 observed. Only HKL reflections observed are of the type $10m \pm L$, $10n \pm L$, L , with m and n integers. The numerous structural absences are explained by twinning; the octahedron consists of four rhombohedral crystals, oriented with their hexagonal c axes along the body diagonals and their hexagonal a axes along the face diagonals of the simulated cubic cell. The twin axis is $[337]$ in rhombohedral notation; twin index 5; twin obliquity 0. The rhombohedral cell ($a = 16.16 \text{ \AA}$, $\alpha = 13^\circ 56'$) contains one Cu₉S₅. The diffraction aspect is R^{**} . The pronounced pseudo-cube, $a' = a/5 = 5.54 \text{ \AA}$, is explained as follows. Only those reflections whose cubic indices HKL are multiples of 5 receive contributions from all four crystals of the twin; they are the only reflections, moreover, to which sulfur atoms contribute. Space group $R\bar{3}m$ leads to a tentative structure in which all atoms lie on the 3-fold axis of the rhombohedral cell, in positions xxx . For the five sulfur atoms, the values of x are: 0, $\pm 1/5$, $\pm 2/5$; for the nine copper atoms: $1/2$, ± 0.060 , ± 0.133 , ± 0.250 , ± 0.350 .

HISTORICAL

Rahlf's (1936) synthesized Cu₉S₅ and took powder patterns at 170° C. He found a face-centered cubic lattice with cell edge equal to $5.575 \pm 0.016 \text{ \AA}$ (\AA from kX) and a cell content of Cu_{7.2}S₄. He also noted that up to 600° C. no transition to a polymorphic form occurs. In a very thorough attempt at elucidating the crystal structure, Rahlf's placed the sulfur atoms at the nodes of the face-centered lattice. This close-packed arrangement is found in a host of sulfide structures, such as ZnS (sphalerite), CaS, PuS, US, which have a cubic cell of about the same size. He tried placing the copper atoms in all the possible holes left by the close-packed sulfur atoms in a way that would keep the symmetry cubic, namely at $\frac{1}{4} \frac{1}{4} \frac{1}{4}$ and $\frac{3}{4} \frac{3}{4} \frac{3}{4}$ in tetrahedral coordination, $\frac{1}{3} \frac{1}{3} \frac{1}{3}$ and $\frac{2}{3} \frac{2}{3} \frac{2}{3}$ in trigonal coordination and $\frac{1}{2} \frac{1}{2} \frac{1}{2}$ in octahedral coordination. No combination of these sites led to any agreement between calculated and observed intensities of the powder pattern, so that Rahlf's was driven to the conclusion that no cubic structure was possible. No further word on the crystal structure of Cu₉S₅ as such has appeared in the literature, but Ross (1954) proposed a theory according to which at least some of the copper atoms in the structure are mobile. Diffuse intensity regions in

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reciprocal space would be predicted on the basis of such a hypothesis. Molé (1954) synthesized crystals of digenite by passing H_2S gas over single crystals of CuCl . He reports obtaining digenite at 800°C . with a pseudo-cubic lattice and cell edge equal to 22.4 \AA . He gives no details as to the true symmetry of his diffraction patterns. (Note that $22.4 = 4 \times 5.6$.)

Buerger (1942) cleared up the confusion that still existed in the mineralogical world concerning the so-called "high-temperature, blue, or isometric chalcocite" by showing that its powder pattern is identical with that of Cu_9S_5 . For this, the only known intermediate compound in the $\text{CuS}-\text{Cu}_2\text{S}$ phase diagram, he proposed to revive the mineral name digenite,¹ a name originally given to a hypothetical compound Cu_5S_4 . In his doctoral dissertation (1940, unpublished) Buerger states: "It is likely that at a temperature of 47°C . or lower the copper atoms become ordered and give rise to another digenite phase."

SYNTHESIS

Digenite was synthesized during a current study of the copper-sulfur system. Chalcocite Cu_2S , digenite Cu_9S_5 , and covellite CuS are the three known compounds in this system. All experiments were carried out in evacuated and sealed silica glass tubes. The copper used in all experiments was standard sample 45C of the National Bureau of Standards (analyzed 99.99% Cu). Sulfur purified to analyze 99.993% S and 0.007% C was kindly supplied by Dr. W. N. Tuller, Superintendent of Laboratory, Freeport Sulphur Co., Port Sulphur, La.

In experiments with copper and sulfur in the atomic ratio of 1:1 and where the charge occupied $\frac{1}{2}$ to $\frac{1}{3}$ of the tube volume, covellite was found to form as the only solid phase up to about 250°C . Above this temperature the dissociation pressure of covellite leads to the formation of a sulfur-rich vapor phase. The copper-to-sulfur atomic ratio in the solid becomes larger than 1:1 and a mixture of digenite and covellite coexists with the vapor. At increasing temperatures digenite, covellite, and vapor, under these specified volume conditions, coexist up to about 400°C . At this temperature all covellite has decomposed, and digenite and vapor are the only phases present. Since covellite is the most sulfur-rich compound in the $\text{Cu}-\text{S}$ system, the maximum temperature at which it can exist in rigid silica tubes was determined by addition of sulfur to the charge. $\text{CuS}+L+V$ were found to coexist up to $507 \pm 3^\circ\text{C}$. Above this temperature $\text{Cu}_9\text{S}_5+L+V$ are stable together. At this invariant point the four phases $\text{Cu}_9\text{S}_5+\text{CuS}+L+V$ are all stable. Starting with copper and sulfur in the atomic ratio of 9:5, digenite still grows at 775°C . The

¹ Ramdohr later proposed the name neodigenite for Cu_9S_5 .

invariant point where the four phases $\text{Cu}_2\text{S} + \text{Cu}_9\text{S}_5 + L + V$ are all stable has as yet not been determined.

With copper and sulfur in the atomic ratio 9:5, the lowest temperature at which digenite was synthesized is 25° C. Reaction between copper and sulfur was noticeable after only 24 hours, but even after 5 months the tubes still contained small amounts of copper and sulfur which had not reacted. At 90° C. all copper had reacted with sulfur to form digenite in about 8 weeks, at 200° C. in about 2 weeks, and at 400° C. in less than 2 days.

Runs containing copper and sulfur in the atomic ratio of 8.5:5¹ and in which the charge occupied about $\frac{1}{3}$ of the tube volume produced digenite and covellite at 300 and 350° C., and digenite and sulfur at 400, 500 and 650° C. This shows that the atomic percentage of sulfur, which is 35.7 in Cu_9S_5 , cannot exceed 37.0 in a digenite solid solution. Runs at 500° C. containing copper and sulfur in the atomic ratio of 9.2:5 produced chalcocite and digenite, showing that if digenite can take up copper in solid solution, the maximum amount, at least at this temperature, is less than 0.5 atomic per cent. The cell dimensions of digenite formed at various temperatures and from mixtures where the copper-to-sulfur ratio varied from 6:5 to 9.5:5 were determined by x-ray diffraction methods. The cell size, however, within the limits of our experimental accuracy (0.3% on lengths) remains constant. "Single crystals" of digenite were produced in more than 30 runs. The crystals used for single-crystal investigations were synthesized at temperatures between 150° C. and 600° C. The digenite "single" crystals always occurred as octahedra, occasionally extremely malformed and frequently modified by small cube faces. Two opposite octahedral faces sometimes predominate over all other faces to such an extent that the crystal looks like a flat hexagonal plate. The crystals vary in size from 10 μ (crystals formed in 4 months at 150° C.) to 4 mm. (crystals formed in the same length of time at 600° C.).

It was observed that, at temperatures above the covellite stability field, digenite crystals grow to a larger size when the copper-to-sulfur ratio is smaller than 9:5, than when the ratio is equal to or larger than 9:5 (but smaller than 2:1).

Accompanying this variation in rate of growth is a striking change in crystal morphology (Figs. 1*a* and 1*b*). Crystals which grow from mixtures where the copper-to-sulfur ratio is smaller than 9:5 have perfectly rounded edges, while those which grow from mixtures where the copper-to-sulfur ratio is larger than 9:5 (but smaller than 2:1) have stepped faces due to oscillation of cube and octahedron. Crystals grown from

¹ Cu and S in atomic ratio 8.5:5 corresponds to 37.0 atomic % S.

mixtures where the copper-to-sulfur ratio is exactly 9:5 show neither of these features.

Digenite was studied on the temperature controlled Norelco diffrac-

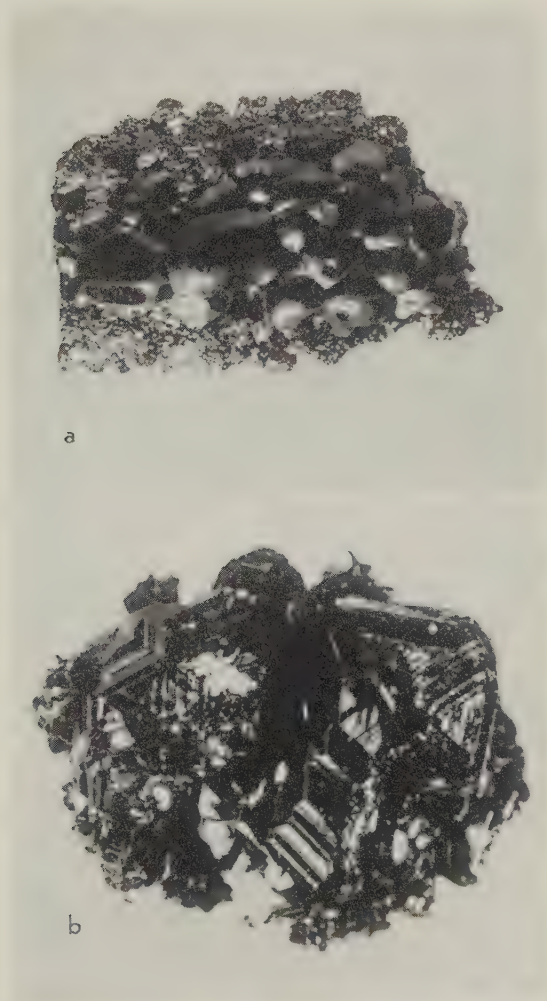


FIG. 1. Crystals of digenite grown at 500° C. for 130 days. (a) Bulk composition Cu_{10}S_5 . Magnification 12 \times . (b) Bulk composition $\text{Cu}_{9.2}\text{S}_5$. Magnification 25 \times .

tometer designed by Mauer and Bolz (1955) at the National Bureau of Standards. We found it to undergo a rapidly reversible and non-quenchable inversion between 60 and 65° C. The flat powder specimen was repeatedly heated and cooled through the inversion temperature, in an

atmosphere of helium to prevent oxidation. The weak reflections of the low-temperature phase, which cannot be indexed on the basis of the 5.57 \AA cubic face-centered cell, disappeared and reappeared each time.

Dr. A. D. Franklin, Ferroelectricity Group, National Bureau of Standards, kindly measured the electrical resistance of digenite while varying the temperature. His preliminary results are not sufficient defi-

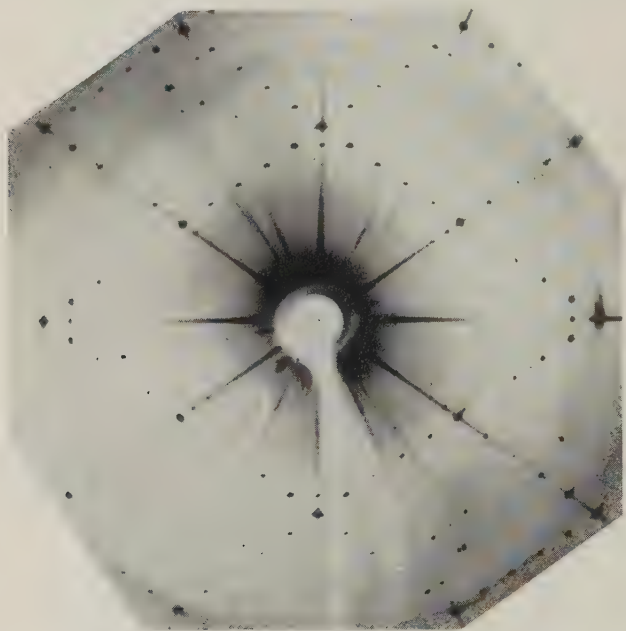


FIG. 2. Precession film $(110)_c^*$ containing reflections HHL ; only reflections of the form $10m \pm L \cdot 10m \pm L \cdot L$ are observed. $\text{Cu K}\alpha$, 15 hours.

nately to confirm the existence of the transition, although they indicate that on cooling a large peak repeatedly appears in the neighborhood of 60° C. in the curve of resistance vs. temperature. He reports that much more precise measurements would be necessary to ascertain the behavior.

X-RAY DATA

We obtained single-crystal patterns with $\text{CuK}\alpha$ ($\lambda = 1.5418 \text{ \AA}$) and $\text{MoK}\alpha$ ($\lambda = 0.7107 \text{ \AA}$) radiations, using the precession as well as rotation and Weissenberg cameras. A precession photograph of $(1\bar{1}0)_c^*$ (Fig. 2) shows that at room temperature $a_c' = 5.54 \pm 0.02 \text{ \AA}$ (subscript c refers to cubic interpretation) is only a pseudo-repeat, albeit a pronounced one. The true repeat appears to be $a_c = 5a_c' = 27.71 \text{ \AA}$. The cell volume is thus multiplied by 125 and the cell content is increased from $0.8 \text{ Cu}_5\text{S}_5$

to $100 \text{ Cu}_9\text{S}_5$. The striking feature of the net $(1\bar{1}0)_c^*$ of the reciprocal lattice is the extremely large number of structural absences: only reflections of the form HHL , with $H = 10m \pm L$ (m integer), are present. A rotation pattern about the a_c axis (Fig. 3) illustrates well the systematic nature of structural absences throughout reciprocal space. Complete indexing of Weissenberg patterns shows that, without exception, all the

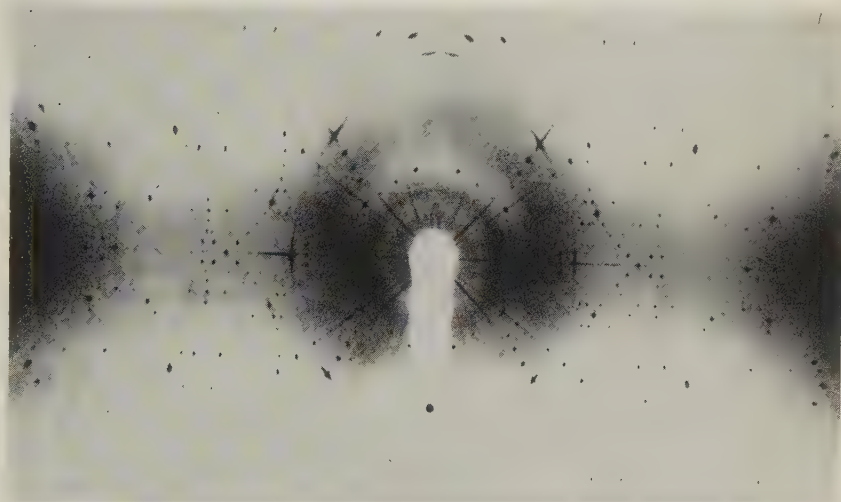


FIG. 3. Rotation pattern about a_c . Note large number of absent reflections on all layer lines. $\text{Cu K}\alpha$, 19 hours.

reflections are of the type $10m \pm L$, $10n \pm L$, L (m, n integers). As the indices of these reflections are all odd or all even, the diffraction aspect is P^{***} .

We faced the problem of placing 900 copper atoms and 500 sulfur atoms in the large face-centered cube in such a way that the observed structural absences would result. This proved to be impossible in any of the permitted space groups.

TWINNING HYPOTHESIS

In a study of sodium peroxide III, Carter and Templeton (1953) had encountered an unusually large number of structural extinctions of x -ray reflections, and a twinning hypothesis had provided a satisfactory interpretation. Dr. David Templeton, to whom we mentioned our problem, immediately suggested that we look into the possibility of twinning. What follows will show how indebted we are to him for this advice.

If our digenite "crystals" are twins, the observed octahedral habit of

the twin can be explained by associating the individual crystals with the body diagonals of the cube. Each crystal must therefore be hexagonal *s.v.*; its lattice can be either hexagonal or rhombohedral. According to the Law of Bravais the axial ratio c/a must be large enough to account for the predominance of the base, which is to form the octahedral face of the twin— $c/a > 0.87$ if the lattice is hexagonal; $c/a > 2.3$ if it is rhombohedral (see nomograms in Mallard, 1879). As to symmetry, the point group of

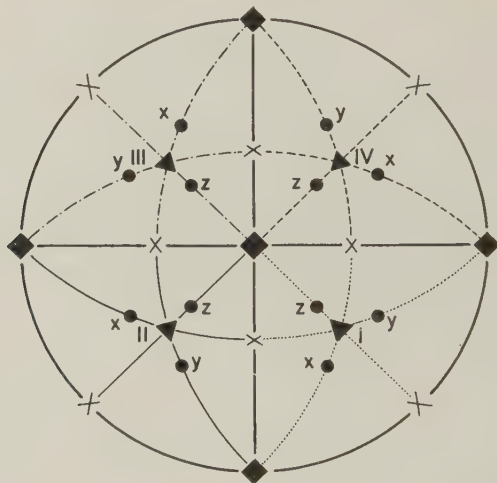


FIG. 4. Stereographic projection of twin on $(001)_c$. The 4-fold twin axis $[001]_c$ brings individuals I, II, III, and IV to coincidence.

the crystal must be a subgroup of the point group of the twin, so that the symmetry operations of the individual crystals, combined with the twin operations, will generate the point group of the twin. If, as in the present case, the observed twin symmetry is $4/m \bar{3} 2/m$, the crystal symmetry must be at least $\bar{3} 2/m$ if the twin operation is a 90° rotation about any of the three 4-fold symmetry axes of the twin or a reflection in any of the mirrors perpendicular to these 4-axes. (Rigorously speaking, provided the crystal lattice were hexagonal, the crystal symmetry could even be a supergroup of $\bar{3} 2/m$, but in this case the additional symmetry operations of the crystal would be lost in twinning and would not appear among the symmetry operations of the twin symmetry $4/m \bar{3} 2/m$.) A stereographic projection on $(001)_c$ (Fig. 4) shows how the symmetry elements of the twin can be subdivided into twin elements, on the one hand, and symmetry elements of four individual crystals, on the other. Let us agree to use $[001]_c$ as 4-fold twin axis, so that crystal I will be brought to coincidence with crystals II, III, IV by clockwise rotations of 90° , 180° , 270° , respectively.

Because the twin lattice extends without deviation throughout the twin edifice, the *twin obliquity* is zero, and we are dealing with twinning by reticular merohedry (Friedel, 1926) on the assumption of a rhombohedral crystal lattice. The twin axis is $[\bar{3}\bar{3}7]$, referred to the rhombohedral axes of each crystal. The *twin index* is 5. This twin arrangement leads to

TABLE 1. TRANSFORMATION OF INDICES

Matrices <i>s</i> : rhombohedral from cubic											
Crystal I			Crystal II			Crystal III			Crystal IV		
.4	.3	.3	.3	. $\bar{4}$	.3	. $\bar{4}$	.$\bar{3}$	.3	. $\bar{3}$	.4	.3
.3	.4	.3	.4	. $\bar{3}$	.3	. $\bar{3}$	.$\bar{4}$	.3	. $\bar{4}$	.3	.3
.3	.3	.4	.3	. $\bar{3}$	.4	. $\bar{3}$	.$\bar{3}$	.4	. $\bar{3}$	.3	.4
Matrices <i>t</i> : cubic from rhombohedral											
Crystal I			Crystal II			Crystal III			Crystal IV		
7	$\bar{3}$	$\bar{3}$	$\bar{3}$	7	$\bar{3}$	7	3	3	3	7	3
$\bar{3}$	7	$\bar{3}$	7	3	3	3	7	3	7	$\bar{3}$	$\bar{3}$
$\bar{3}$	$\bar{3}$	7	$\bar{3}$	$\bar{3}$	7	$\bar{3}$	$\bar{3}$	7	$\bar{3}$	$\bar{3}$	7

the following *s* matrices (Int. Tab., Vol. I, 1951, p. 15), that must be used to obtain rhombohedral indices *hkl* from cubic ones *HKL*, one matrix for each of the four individuals. The inverse *t* matrices permit us to obtain cubic indices *HKL* from rhombohedral ones, *hkl* (Table 1).

The explanation of the cubic absences follows at once. Let us designate by $H_j K_j L_j$ the cubic indices of a given *hkl* reflection coming from the *j*th crystal, *j* = I, II, III, IV. The *t* matrices (Table 1) give, setting $s = 3(h + k + l)$:

$$\begin{array}{lll}
 H_I = 10h - s, & K_I = 10k - s, & L_I = 10l - s, \\
 H_{II} = 10k - s, & K_{II} = -(10h - s), & L_{II} = 10l - s, \\
 H_{III} = -(10h - s), & K_{III} = -(10k - s), & L_{III} = 10l - s, \\
 H_{IV} = -(10k - s), & K_{IV} = 10h - s, & L_{IV} = 10l - s.
 \end{array}$$

We drop the subscript from the *L* index and substitute $(10l - L)$ for *s* in the expressions of H_j and K_j . We thus obtain, setting $m = h - l$ and $n = k - l$:

$$\begin{array}{lll}
 H_I = 10m + L, & K_I = 10n + L, & L_I = L, \\
 H_{II} = 10n + L, & K_{II} = -(10m + L), & L_{II} = L, \\
 H_{III} = -(10m + L), & K_{III} = -(10n + L), & L_{III} = L, \\
 H_{IV} = -(10n + L), & K_{IV} = 10m + L, & L_{IV} = L.
 \end{array}$$

accuracy, the four individuals of the twin must have equal volumes. No twin boundaries were observed, either under the microscope or in polished sections viewed in reflected light, so that twinning is presumably of the intimate penetration type. This conclusion is confirmed by the observation that several chips broken from large twins give diffraction pat-

TABLE 2. REFLECTIONS CONTRIBUTING TO SPOT 5.15.15 ON ROTATION PATTERN ABOUT $[001]_c$

Cubic Indices	Rhombohedral Indices											
	Crystal I			Crystal II			Crystal III			Crystal IV		
5 15 15	11	12	12	0	2	3	2	3	0	9	7	9
15 5 15	12	11	12	7	9	9	3	2	0	2	0	3
5 15 15	7	9	9	3	2	0	2	0	3	12	11	12
15 5 15	0	2	3	2	3	0	9	7	9	11	12	12
5 15 15	2	0	3	12	11	12	7	9	9	3	2	0
15 5 15	9	7	9	11	12	12	0	2	3	2	3	0
5 15 15	2	3	0	9	7	9	11	12	12	0	2	3
15 5 15	3	2	0	2	0	3	12	11	12	7	9	9

terns with identical relative intensities. (The good octahedral cleavage reported by Rahlfs for the high-temperature digenite is missing in all our specimens.)

The appearance of a pronounced pseudo-repeat $a'_c = 5.54 \text{ \AA}$ is explained by the twinning interpretation. The reflections giving the pseudo-repeat are those with cubic indices hkl , of the form $10m \pm L$, $10n \pm L$, L , with L a multiple of 5, corresponding to two or more sets of rhombohedral reflections hkl with $h+k+l=5n$. They are the only ones to which more than one rhombohedral reflection contributes its intensity. These reflections are also the only ones for which the contributions from the sulfur atoms do not cancel one another, but have maximum positive amplitude (Table 2). We should therefore not be surprised that, with only a few exceptions, these reflections are the only ones found on the powder chart between $2\theta = 20^\circ$ and $2\theta = 70^\circ$. The exceptions correspond, on the precession pattern (Fig. 2), to the strongest two reflections other than the reflections of Rahlfs' pseudo-cell, namely $119_c = 223_{rh}$ ($d = 3.05 \text{ \AA}$) and $991_c = 665_{rh}$ ($d = 2.17 \text{ \AA}$). It is surprising that Buerger (1942) did not report these two reflections for the room-temperature form, since they are more intense than some of the lines which he did observe, such as his 222, which is $10.10.10_c$ referred to the large cube. Dr. Virginia Ross (priv. comm., March 1, 1957) writes: "N. Buerger's

x-ray patterns of digenite, as well as my own patterns of substituted phases that are related to digenite, exhibit lines at low temperature which alternately appear and disappear on heating and cooling."

The impossibility of finding a cubic structure and the abundance of absent reflections on "single crystal" diffraction patterns are thus explained; digenite is rhombohedral. Its aspect is R^{**} , its cell dimensions,

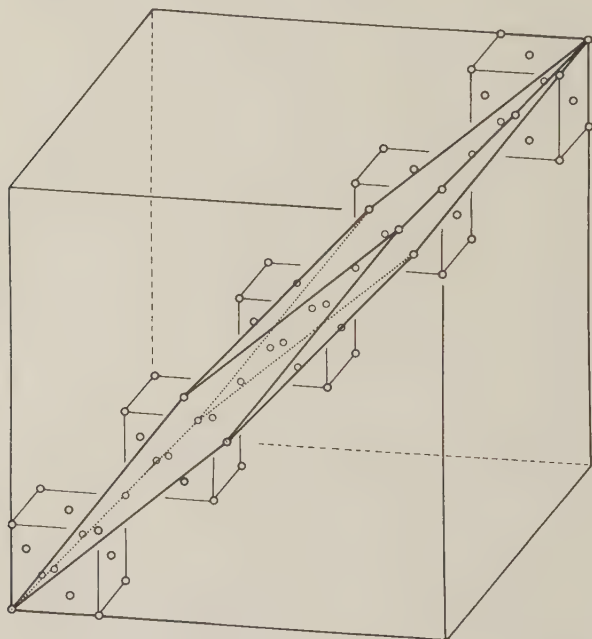


FIG. 6. Rhombohedral cell in relation to large and small cubic cells.

referred to hexagonal axes, are: $a_{\text{hex}} = a_c \sqrt{2}/10 = 3.92$, $c_{\text{hex}} = a_c \sqrt{3} = 48.0$ Å, $(c/a)_{\text{hex}} = \sqrt{150} = 12.25$, $V_{\text{hex}} = 3a_c^3/100$ Å³. Since the large cubic cell contains 100 Cu_9S_5 , the hexagonal cell contains 3 Cu_9S_5 . The rhombohedral cell has dimensions $a_{\text{rh}} = \frac{1}{3}\sqrt{c_{\text{hex}}^2 + 3a_{\text{hex}}^2} = 16.16$ Å, $\alpha = 13^\circ 56'$ (Fig. 6). It contains one Cu_9S_5 .

The remarkable pseudo-symmetry of digenite, on the other hand, remains a puzzle. The $(c/a)_{\text{hex}}$ ratio stays exactly equal to $\sqrt{150}$ up to the inversion temperature; any slight deviation would lead to a splitting of powder lines, and such splitting is not observed. This means that the rhombohedral lattice can be referred to a supercell, which is *metrically cubic* throughout the stability range of the phase. The diffraction patterns, obtained from the twin, moreover, indicate cubic *symmetry*. One

is almost tempted to conclude that the crystal must be cubic. But it is not! We are dealing here with what might be called a case of high-order merohedry.¹

A glance at *Crystal Data* (Donnay and Nowacki, 1954, p. 466) reveals that the only compound with approximately the same cell as digenite is wurtzite-15R, ZnS. The latter was studied by Frondel and Palache (1950). It occurs as *untwinned* single crystals. Its cell dimensions are $a_{\text{hex}} = 3.83$, $c_{\text{hex}} = 46.88$ Å (from kX), $c/a = 12.24$; its space group $R\bar{3}m$ is obtained from x-ray results and morphological evidence. The content of the rhombohedral cell is given as Zn_5S_5 , which is surprisingly different from Cu_9S_5 in view of the nearly equal cell volumes. The density was not reported; it could not be determined for lack of material. We were unable to obtain any specimen of this type of ZnS.

A crystalline edifice, with the composition of the ternary compound in the Ni-Cu-Al system, remarkably similar to that of digenite, has recently been described by Bown (1956). This author was fortunate in finding single crystals of a rhombohedral species ($a = 13.53$ Å, $\alpha = 17^\circ 27'$, $V = 194.4$ Å³), on which he determined the crystal structure. In addition he describes a cubic species, which he considers a second form, with the reservation, however, that its pattern of reflections is "very nearly identical with that which would be given by a four-component multiple twin of the rhombohedral form, with the four triad axes parallel to the triads of a cube." Bown is inclined to think that the phenomenon is not one of twinning and he is going to investigate "the relation between the two forms."

CRYSTAL STRUCTURE

All attempts at growing single crystals of digenite failed, even though syntheses were made under varying conditions of temperature, rates of heating and cooling, bulk composition, etc. Only twins could be produced. Hope of obtaining single-crystal data for the determination of the crystal structure thus had to be abandoned, and our first problem was to find out how to extract, from the intensities yielded by the twinned edifice, the necessary F_{obs} -values of one individual crystal.

¹ High-order merohedry (*mériédrie d'ordre supérieur*) is the term given (Friedel, 1926, p. 56) to a situation where the point-group symmetry of the lattice not only is higher than that of the crystal (as in the usual cases of merohedry) but is more so than necessary. For instance, a crystal with symmetry 222 normally has a lattice with point group $2/m\ 2/m\ 2/m$; this crystal is merohedral. If its cell had two of its edges rigorously equal, say $a = b$, and equal at all temperatures, the lattice symmetry would be $4/m\ 2/m\ 2/m$. The point group 222 of such an orthorhombic crystal with a tetragonal lattice would then be called a high-order merohedry. As Friedel remarks, measurements cannot *prove* the existence of high-order merohedry.

On Weissenberg and precession films, the only strong reflections are the reflections that can be indexed on the small cubic pseudo-cell; all others are too weak to be measurable. This observation determines the choice of the experimental method; only on rotation patterns taken about the 4-fold twin axis $[001]_c$ do the weak reflections become sufficiently enhanced (by the multiplicities conferred on them by the rotation and by twinning) to be measurable by visual comparison.

TABLE 3. REFLECTIONS CONTRIBUTING TO SPOT 1.9.11 ON
ROTATION PATTERN ABOUT $[001]_c$

Cubic Indices	Rhombohedral Indices			
	Crystal I	Crystal II	Crystal III	Crystal IV
1 9 11		012		
9 1 11				102
$\bar{1}$ 9 11			102	
$\bar{9}$ 1 11	012			
1 $\bar{9}$ 11	102			
9 $\bar{1}$ 11			012	
$\bar{1}$ $\bar{9}$ 11				012
$\bar{9}$ $\bar{1}$ 11		102		

The rotation pattern of the twin was first indexed with reference to the large cubic cell. The reflections with cubic indices H , K , L all multiples of 5 are due to more than one rhombohedral reflection hkl with $(h+k+l)$ divisible by 5, as shown by an example (Table 2). Such reflections cannot be used for intensity data. All other reflections can be used, for the following reasons. If $H \neq K$, as in the cubic reflection 1.9.11 for instance (Table 3), each crystal contributes the same two equivalent rhombohedral reflections; the multiplicity of the cubic reflection is therefore 8. If $H = K$ each crystal contributes one and the same reflection; and the multiplicity of the cubic reflection is 4. By dividing the measured intensity by 8, if $H \neq K$, or by 4, if $H = K$, intensities can be assigned to certain rhombohedral reflections; these intensities can be used as if they had been obtained from an isolated single crystal, provided the volumes of the component crystals in the twin are equal. The intensities were corrected for Lorentz and polarization factors.

It is convenient to discuss the crystal structure with reference to the rhombohedral axes, because they lead to a primitive cell. It is, moreover, helpful to recognize the division of the long body diagonal of this cell into five equal parts, each part representing the body diagonal of a small cube of edge 5.54 \AA (Fig. 6), subsequently referred to as a cubelet.

The first fact to give a clue to the crystal structure is the steepness of the rhombohedral cell. It requires all atoms to be placed along the 3-fold axis of the cell, in positions xxx . The reasons given by Rahlfs for placing the sulfur atoms at the nodes of the face-centered cubelets are still valid; the sulfur atoms build a framework in cubic close packing. In rhombohedral positions xxx , they lie at $x=0$, $x=\pm\frac{1}{5}$, and $x=\pm\frac{2}{5}$. That these positions correspond to those chosen by Rahlfs can be seen by inspection of Fig. 6 or by applying the transposed matrix t to the cubic co-ordinates of sulfur atoms. All the sulfur atoms not listed above, which fall at the nodes of the five face-centered cubelets, belong to adjacent rhombohedral cells. For example: $\pm(.4\ .3\ .3, .3\ .4\ .3, .3\ .3\ .4)_c$ become the origins of adjacent cells $\pm(100, 010, 001)_{rh}$, etc.

The placement of copper atoms is a task quite similar to that faced by Rahlfs. Because the atoms can only occupy positions xxx , the five rhombohedral space groups compatible with diffraction aspect R^{**} can be divided into two categories on the basis of the multiplicity of the xxx position. In $R3m$ and $R3$ the position has multiplicity one; in $R\bar{3}m$, $R32$, and $R\bar{3}$, it has multiplicity two and $\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}$ is the only one-fold position available. We have no evidence for the absence of the center of symmetry, pyroelectric tests at liquid nitrogen temperature are negative, and we therefore proceed with the holohedral space group $R\bar{3}m$. (For the special positions xxx , space groups $R32$ and $R\bar{3}$ are undistinguishable from $R\bar{3}m$.) One copper atom is located at $x=\frac{1}{2}$, in the one-fold position; the others are found by trial and error approximately at $x=\pm 0.060$, $x=\pm 0.133$, $x=\pm 0.250$, and $x=\pm 0.350$.

This structure must be considered tentative. On those reflections that can be used in the crystal-structure determination, as explained above, the agreement between calculated and observed intensities is only moderately satisfactory. It still leaves much to be desired. The S—S distance is equal to 3.92 Å. At $x=\frac{1}{2}$ copper is octahedrally coordinated to sulfur atoms; at $x=\pm 0.060$ copper lies in tetrahedral coordination, but is slightly displaced from the center of the tetrahedron toward one of its faces; at $x=\pm 0.133$ copper lies in triangular coordination; at $x=\pm 0.250$ and at $x=\pm 0.350$, copper is in regular tetrahedral co-ordination. The Cu—S distance ranges from 2.26 Å for copper in triangular co-ordination to 2.77 Å for copper in octahedral co-ordination. If the crystal structure were of the ionic type, the formula of low-temperature digenite should be written $CuS \cdot 4Cu_2S$; in which the cupric ion would correspond to the octahedrally co-ordinated copper.

The crystal structure throws light on the twin structure. If the sulfur atoms lie rigorously at the nodes of a face-centered cubic lattice, the twinning by high-order merohedry is immediately explained; the cubelet

is the cell of the twin lattice. We also note that the cell of the twin lattice is smaller than that of the crystal lattice; it is a *subcell* (or submultiple cell) of the crystal lattice. Geometrically the cell of the twin lattice could be taken to be the large cube instead of the cubelet; it would then be a *supercell* (or multiple cell) of the crystal lattice. Friedel (1926) used the supercell in his treatment of twinning; Wrinch (1952), the subcell. In the present case, the subcell is much preferable to the supercell because it possesses real structural significance; it expresses the periodicity of the sulfur atoms.

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REFERENCES

- BOWN, M. G. (1956), *Acta Cryst.* **9**, 70.
BUERGER, N. W. (1940), Ph.D. dissertation, Mass. Inst. Technology.
——— (1941), *Econ. Geol.* **36**, 19.
——— (1942), *Am. Mineral.* **27**, 712.
CARTER, G. F., AND TEMPLETON, D. H. (1953), *J. Am. Chem. Soc.* **75**, 5247.
DONNAY, J. D. H., AND NOWACKI, W. (1954), Crystal Data. *Geological Society of America, Memoir* **60**.
FRIEDEL, G. (1926), *Leçons de Cristallographie professées à la Faculté des Sciences de Strasbourg*. Paris: Berger-Levrault.
FRONDEL, C., AND PALACHE, C. (1950), *Am. Mineral.* **35**, 29.
International Tables for X-ray Crystallography (1952), vol. 1, edited by Henry, N. F. M., and Lonsdale, K. Birmingham: Kynoch Press.
MALLARD, E. (1879), *Traité de Cristallographie*, vol. 1, Paris: Dunod.
MAUER, F. A., AND BOLZ, L. H. (1955), *WADC Tech. Rept.* 55-473.
MOLÉ, R. (1954), Thèses No. d'ordre 371. Paris: Masson.
RAHLFS, P. (1936), *Z. phys. Chem.*, B., **31**, 157.
ROSS, V. (1954), *Econ. Geol.* **49**, 734.
WRINCH, D. (1952), *Am. Mineral.* **37**, 234.

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X-RAY STUDIES OF SYNTHETIC COFFINITE, THORITE AND URANOTHORITES*

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ABSTRACT

X-ray data are presented for synthetic coffinite, thorite, and several uranothorites. The cell constants obtained for coffinite are $a = 6.981 \pm 0.004$ kX, $c = 6.250 \pm 0.005$ kX; for thorite $a = 7.128 \pm 0.004$ kX, $c = 6.314 \pm 0.003$ kX. Intermediate constants determined for several uranothorites indicate a continuous solid solution between USiO_4 and ThSiO_4 . Coffinite and thorite are isostructural with zircon; the space group is $D_{4h}^{19} - I_4/a md$. The oxygen positions for coffinite are $u = 0.180 \pm 0.010$, $v = 0.347 \pm 0.010$ and for thorite $u = 0.166 \pm 0.010$, $v = 0.347 \pm 0.010$. No changes were observed either in line intensities or in cell constants when (OH) was removed from the hydrothermal preparations.

The mineral coffinite, described as a uranous silicate with hydroxyl substitution, was identified on the basis of the similarity of its x-ray powder pattern to that of zircon (ZrSiO_4) or thorite (ThSiO_4) (Stieff, Stern and Sherwood, 1956). Pabst (1951) obtained single crystal patterns of a New Zealand detrital uranothorite (11.5 wt% UO_2) and determined the space group to be the same as given for zircon. A similar assignment was made by Bonatti and Gallitelli (1951) on detrital thorite crystals from Nettuno Rome.

Although coffinite is isostructural with zircon and thorite, the naturally occurring mineral is reported to exist as the hydroxyl substituted form of USiO_4 (Stieff, Stern and Sherwood, 1956). This consideration is based on the low silicon content which appears in the analyses of the mineral. However, our observations on a synthetic product (Hoekstra and Fuchs, 1956) indicate that neither cell dimensions nor line intensities appear to be modified when water is removed, suggesting therefore that the synthesized product may be USiO_4 without hydroxyl substitution. Infrared examination of heated samples made in this laboratory clearly indicate that water has been expelled (Hoekstra and Fuchs, to be published).

In addition to coffinite, we have synthesized thorite and some uranothorites. The thorite can be prepared by a hydrothermal process or from the melt (Fuchs, 1958). The latter process yields water-free samples, and again it does not seem possible to distinguish between hydroxyl-containing and hydroxyl-free samples on the basis of x-ray powder patterns.

Powder data for the synthesized coffinite and thorite are presented in Table I. Cell dimensions and x-ray densities for these samples are given

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

TABLE I. X-RAY DATA FOR COFFINITE AND THORITE. $\text{CuK}\alpha_{1,2}=1.5386\text{ kX}$

Coffinite					Thorite				
<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_o	I_e	<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_o	I_e
101	0.02758	0.02750	197	214	101	0.02669	0.02666	174	208
200	.04917	.04912	203	227	200	.04711	.04712	210	249
211	.07636	.07653	96	105	211	.07348	.07357	99	111
112	.08540	.08538	196	184	112	.08287	.08299	162	188
220	.09784	.09792	53	58	220	.09376	.09376	63	68
202	.1097	.1098	9	5	202	.1065	.1064	6	4
301	.1252	.1252	62	54	301	.1202	.1202	63	57
103	.1489	.1490	60	38	103	.1456	.1456	42	40
321	.1737	.1739	69	58	321	.1672	.1669	67	63
312	.1827	.1829	144	141	312	.1765	.1764	135	140
400	.1964	.1953	66	67	400	.1870	.1870	40	34
213		.1977			213	.1924	.1922	33	39
411	.2227	.2226	32	25	411	.2138	.2134	25	24
004	.2437	.2429	53	53	420	.2335	.2335	39	35
420		.2440			004	.2383	.2378	18	19
303		.2464			303		.2388		
402	—	.2559	0	<1	402	—	.2462	0	<1
332	.2802	.2802	47	37	332	.2695	.2694	38	39
204	.2913	.2916	48	30	204	.2847	.2843	36	41
323	.2948	.2951	10	12	323		.2854		
422	—	.3045	0	<1	422	—	.2926	0	0
501	0.3200	0.3199	34	29	501	0.3066	0.3064	27	30
431					431				
224	.3405	.3402	47	45	224	.3315	.3309	36	43
413	.3433	.3437			413		.3318		
314	—	.3646	0	<1					
521	.3684	.3685	15	10	521	.3534	.3529	10	11
					314	—	.3541	0	<1
512	.3777	.3774	36	38	512	.3627	.3624	38	39
440	.3906	.3898	18	14	440	.3732	.3728	8	8
105		.3914			105	.3829	.3828	5	5
404	.4390	.4375	56	52	600	.4193	.4193	12	11
600		.4383			404	.4245	.4239	26	29
215		.4400			433		.4248		
503		.4409			503		.4248		
433		.4409			215		.4293	14	12
611	.4649	.4655	13	9	611	.4466	.4457	11	9
532	.4753	.4745	37	30	532	.4557	.4553	27	31
424	.4870	.4860	60	59	620	.4657	.4658	17	16
620		.4868			424	.4705	.4703	33	42
305		.4886			523		.4713		
523		.4894			602	—	.4785	0	0
					541	.4928	.4922	7	7
602	—	.4988	0	<1					

TABLE 1. (continued)

Coffinite					Thorite				
<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_0	I_e	<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_0	I_e
541	.5145	.5141	9	7	325	.5227	.5224	7	7
325	.5380	.5372	10	8	622	—	.5245	0	<1
622	—	.5474	0	<1	631	.5395	.5388	9	10
514	—	.5589	0	<1	514	—	.5398	0	0
631	.5628	.5626	14	10	116	.5573	.5576	10	14
116	.5697	.5701	20	14	613	.5649	.5644	9	10
415	.5866	.5858	17	18	415	.5682	.5690	7	9
613		.5865			206	—	.5809	0	<1
206	—	.5944	0	<1	701	.5863	.5854	3	3
701	.6122	.6111	6	4	640	.6051	.6055	12	13
444	.6340	.6317	29	34	444	.6099	.6094	15	21
640		.6324			543		.6103		
543		.6350			721		.6320		
534	—	.6560	0	<1	534	—	.6329	0	<1
721	.6601	.6596	14	9	552	α_1	.6411	20	22
316	.6684	.6672	56	56	712		.6408		
552		.6685			552	α_2	.6424	13	10
712		.6685			712		.6439		
604	.6827	.6802	28	27	316 α_1	.6501	.6501	14	14
505		.6829			604		.6559		
435		.6829			633	α_2	.6566	13	10
633		.6836			505		.6568		
642	—	.6928	0	<1	435	α_1	.6607	10	7
624		.7287			642		.6641		
525	.7304	.7314	32	39	624 α_1	.7023	.7024	0	<1
703		.7320			703		.7034		
406	—	.7400	0	<1	624 α_2	.7059	.7055	28	27
107	.7564	.7548	10	10	525 α_1	.7090	.7080	6	6
651		.7567			406		.7206		
336	.7660	.7643	33	38	651 α_1	.7247	.7243	8	7
732		.7656			107		.7272		
800	.7803	.7779	14	15	732 α_1	.7336	.7339	15	17
723		.7806			732 α_2		.7374		
426	—	.7885	0	<1	336	α_1	.7431	10	11
217		.8025			800		.7437		
811		.8036			723 α_1	.7493	.7443	8	5
741	α_1	.8036	21	18	426		.7671		
217		.8053			811	α_1	.7715	8	9
811	α_2	.8075	17	21	741		.7708		
741		.8075			811	α_2	.7746	6	6
820	.8281	.8265			217 α_1		.7847		
615		.8285			820 α_1	.7915	.7908	8	8

TABLE 1. (continued)

Coffinite					Thorite				
<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_0	I_c	<i>hkl</i>	$\sin^2 \theta$ obs.	$\sin^2 \theta$ calc.	I_0	I_c
802	—	.8385	0	<1					
714	—	.8502	0	<1					
307	.8517	.8518	8	5	820 α_2	.7951	.7948		
516 α_1	.8610	.8601			615 α_1	.8021	.8010	5	5
			36	38	802	—	.8046	0	<1
					307		.8319	0	4
516 α_2	.8646	.8639			516		.8361		
					660	.8363	.8374		
					714		.8189		
644		.8744			516		.8393		
660	.8769	.8751	.8761		660	.8421	.8415	.8404	
545		.8771			644		.8420		
653		.8778			653	.8421	.8429	.8424	
822	—	.8871							
327		.9004			644		.8457		
831	.9018	.9024	.9014		653	.8467	.8468	.8463	
635		.9257			545 α_1	.8467	.8475		
743	.9258	.9264	.9262		822	—	.8501		
813		.9264			545 α_2	.8525	.8510		
734	—	.9474			831 α_1	.8641	.8638		
417	.9480	.9490							
536		.9586			831 α_2	.8682	.8680		
752	.9585	.9600	.9593		327 α_1	.8773	.8777		
840		.9723			327 α_2	.8815	.8807		
705	.9729	.9743			743		.8893	.8894	
606	—	.9831			813				
					743		.8939	.8935	
					813				
					635 α_1	.8939	.8946		
					734	—	.9120		
					752 α_1	.9202	.9199		
					752 α_2		.9243		
					417 α_1	.9247	.9242		
					536		.9292	.9298	
					840		.9304		
					536		.9328		
					840	.9345	.9350	.9339	
					705 α_1	.9402	.9405		
					008 α_1	.9485	.9489		
					606	—	.9535		
					901 α_1	.9574	.9569		
					901 α_2	.9622	.9616		
					804		.9815		
					833	.9818	.9824	.9820	
					804		.9860		
					833		.9871	.9866	

TABLE II. CELL DIMENSIONS AND DENSITIES OF COFFINITE, THORITE AND URANOTHORITES

Material	<i>a</i>	<i>c</i>	<i>a/c</i>	ρ gm./cm. ³ calc.
USiO ₄ *	6.981 ± .004 kX	6.250 ± .005 kX	1.1170	7.15 ± 0.02
3 USiO ₄ · ThSiO ₄	7.007 ± .005	6.275 ± .003	1.1167	7.04 ± .02
USiO ₄ · ThSiO ₄	7.039 ± .003	6.294 ± .002	1.1184	6.91 ± .01
USiO ₄ · 3 ThSiO ₄	7.071 ± .002	6.314 ± .003	1.1199	6.80 ± .01
ThSiO ₄	7.128 ± .004	6.314 ± .003	1.1289	6.67 ± 0.01

* A value previously reported for USiO₄ (Hoekstra and Fuchs, 1956), varies slightly from the value given here, since the earlier value was based on an incomplete indexing of the powder pattern.

in Table II. We also include in this table *x*-ray data for the several uranothorite samples which were prepared by the hydrothermal process developed for coffinite. The only variation in technique involves the preparation of thorium and uranium tetrachloride solutions in the desired concentrations. Reference to Table II shows that the cell dimension changes are uniform throughout the composition range.

We have also attempted to determine the oxygen positions in coffinite and thorite from powder patterns. Although the oxygen scattering is very small, the assigned positions are necessary in order to obtain reasonable agreement between observed and calculated intensities.

The atomic positions are assumed to be those for zircon, D_{4h}^{19} — I_4/a *md* and are as follows:

4 Th or 4 U in (*a*)

4 Si in (*b*)

16 O in (*h*) (International Tables)

The only variables are *u* and *v* for oxygen and these were determined by trial methods. The resulting values for the oxygen positions are given in Table III. The extent of agreement between observed and calculated intensities is shown in Table I. The observed intensities were deduced from microphotometer tracings and the calculated intensities were obtained from the formula

$$I \sim F^2 p \frac{1 + \cos^2 2\theta}{\sin^2 \theta \cos \theta}$$

TABLE III. OXYGEN POSITIONS

	<i>u</i>	<i>v</i>
USiO ₄	.180 ± 0.010	.347 ± 0.010
ThSiO ₄	.166 ± 0.010	.347 ± 0.010

TABLE IV. BOND LENGTHS

USiO ₄	U—4 O	2.32 Å ± .08 Å
	U—4 O	2.52 Å ± .09 Å
	Si—4 O	1.58 Å ± .09 Å
ThSiO ₄	Th—4 O	2.46 Å ± .08 Å
	Th—4 O	2.50 Å ± .09 Å
	Si—4 O	1.55 Å ± .09 Å
ZrSiO ₄	Zr—4 O	2.05 Å
	Zr—4 O	2.41 Å
	Si—4 O	1.62 Å

where p is the multiplicity factor and the other quantities have their usual significance.

The bond distances which result are shown in Table IV. The bond lengths in zircon (Wyckoff and Hendricks, 1927) are given for comparative purposes.

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REFERENCES

- BONATTI, S., AND GALLITELLI, P. (1951) Sulla torite di Nettuno (Roma): *Atti. Soc. toscani Sci. Nat. (Pisa) Mem., (Series A)*, **57**, 182–183.
- FUCHS, L. H. (1958) Formation and Properties of Synthetic Thorite Crystals: this issue, page 367.
- HOEKSTRA, H. R. AND FUCHS, L. H. (1956) Synthesis of Coffinite—USiO₄: *Science*, **123**, 105.
- HOEKSTRA, H. R., AND FUCHS, L. H., to be published.
- International Tables for X-Ray Crystallography* (1952), Vol. 1, International Union of Crystallography, Birmingham, England, Kynock Press.
- PABST, A. (1951) X-Ray Examination of Uranothorite: *Am. Mineral.*, **36**, 557–562.
- STIEFF, L. R., STERN, T. W. AND SHERWOOD, A. M. (1956) Coffinite, a Uranous Silicate with Hydroxyl Substitution: A New Mineral: *Am. Mineral.*, **41**, 675–688.
- WYCKOFF, R. W. G. AND HENDRICKS, S. B. (1927) Die Kristallstruktur von Zirkon und die Kriterien für spezielle Lagen in tetragonalen Raumgruppen: *Z. Krist.* **66**, 73–102.

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PIEZOBIREFRINGENCE IN SILICON*

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ABSTRACT

A stress-birefringence investigation has been carried out on high purity silicon at a wavelength of 1.11μ . Values have been obtained for the piezobirefringence constants ($q_{111}-q_{112}$) and $2q_{1212}$. The linearity of the stress-optical relationship in silicon has been established up to stresses of approximately 450 kilograms/cm². A qualitative indication has been obtained of the directions of change in the index of refraction of silicon under a stress applied parallel to [100]. Various transmission curves are given for World War II surplus infrared image converter tubes with Si, Si+H₂O, and Si+ Corning No. 5850 filters, respectively. An observation is noted on orders of interference resulting from the use of non-monochromatic infrared light analogous to the orders of interference colors commonly observed with visible white light.

INTRODUCTION

Thorough reviews of the field of study concerned with the stress-optical behavior of crystalline materials have been given by both Poin-dexter (1) and Giardini (2). The present paper reports on the stress-birefringence of high purity silicon at a wavelength of 1.11μ .

The silicon used in this investigation was obtained from the Army Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey. The boule from which specimens were cut was elongated (pulled) parallel to [111]. Some spinel-type twinning was present in the boule; however, specimens were taken from areas free of twinning. The latter was determined both by visual inspection of specimen surface and by x-ray diffraction. No quantitative information is available on the purity of the silicon other than it is described as "high purity" material.

Since silicon possesses $m3m$ symmetry, only constants q_{111} , q_{112} and q_{1212} are required for a complete description of stress-optical behavior (3, 4). Although definitions and derivations of these constants can be found in either reference (1) or (2) given above, they will be redefined here for the sake of completeness.

The stress-optical constant q_{111} describes the relationship between a homogeneous stress directed along the crystallographic axis $X_1\bar{X}_1$ and the resulting retardation of light vibrating parallel to and traveling perpendicular to $X_1\bar{X}_1$. The stress-optical constant q_{112} defines the relationship between a homogeneous stress directed along $X_1\bar{X}_1$ and the induced retardation of light vibrating parallel to $X_2\bar{X}_2$ and traveling parallel to $X_3\bar{X}_3$. The value ($q_{111}-q_{112}$) constitutes the stress-optical difference or piezobirefringence constant. The constant $2q_{1212}$ describes the relationship

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between a homogeneous stress directed along X_{12} (along $2/m$ for symmetry class $m3m$) and the resulting difference in retardation of light vibrating parallel to $X_1'\bar{X}_1'^*$ and $X_2'\bar{X}_2'^*$,* and traveling parallel to $X_3\bar{X}_3$. Constant $2q_{1212}$, therefore, constitutes a piezobirefringence constant for crystals possessing $m3m$ symmetry.

Values for both piezobirefringence constants ($q_{1111}-q_{1122}$) and $2q_{1212}$, at a wavelength of $1.11\ \mu$ have been determined and will be presented later in this report.

SPECIMEN PREPARATION

Polished oriented rectangular parallelepiped specimens are generally preferred for piezobirefringence investigation. The equipment and procedures which were used for orienting and cutting silicon are described in this issue on page 370.

For the measurement of the difference constant ($q_{1111}-q_{1122}$), a parallelepiped was prepared having all crystallographic cube faces, and dimensions $0.312\text{ cm.} \times 0.4145\text{ cm.} \times 0.518\text{ cm.}$ For the determination of $2q_{1212}$, a parallelepiped was cut having a zone of four dodecahedral faces terminated by a pair of parallel cube faces. The dimensions of the cube faces are $0.648\text{ cm.} \times 0.574\text{ cm.}$ and that common to the dodecahedral faces is 0.284 cm. The crystallographic orientation of both specimens is accurate to within 15 minutes of arc. The parallelism of opposing sides of the parallelepipeds are correct to within 1 minute of arc.

In order to investigate the absolute change in index of refraction as a function of stress applied parallel to $[100]$, a silicon specimen was prepared in the form of a prism frustum. The right trapezium faces of the prism were crystallographic (100) faces with the following dimensions: base = 0.890 cm. , altitude = 0.393 cm. , second altitude = 0.160 cm. , hypotenuse = 0.920 cm. The included prism angle, as determined by optical goniometry, is $14^\circ 36.5'$. The frustum is preferred to a right triangular type of prism because of its superior structural configuration.

Polishing of the oriented specimens was carried out with the following abrasive media in the order listed: 1) 350 grit SiC paper mounted on plate glass, 2) 500 grit SiC paper mounted on plate glass, 3) 8-25 micron diamond powder suspended in cold cream and spread on a sheet of index card paper which in turn is mounted on plate glass, 4) same as 3) but with 4-8 micron diamond powder, 5) same as 3) but with $\frac{1}{2}$ -3 micron diamond powder. Each stage requires roughly about 1-2 minutes of polishing with a light hand pressure. Both the specimen and hands must be thoroughly cleansed before proceeding from one stage to the next.

* Directions $X_1'\bar{X}_1'$ and $X_2'\bar{X}_2'$ are respectively parallel to and normal to X_{12} and in the plane of crystallographic directions $X_1\bar{X}_1$ and $X_2\bar{X}_2$.

The above procedure has been found to produce a good quality optical surface on silicon.

INSTRUMENTATION

A schematic view of the experimental apparatus used to determine the values of the piezobirefringence constants of silicon is given in Fig. 1. The light source consists of a General Electric 6 volt, 54 watt vertical tungsten ribbon lamp. A wide aperture lens system was used to collimate the light into a parallel beam and direct it through a nicol prism polarizer. The vibration direction of the polarizer is oriented 45° from verti-

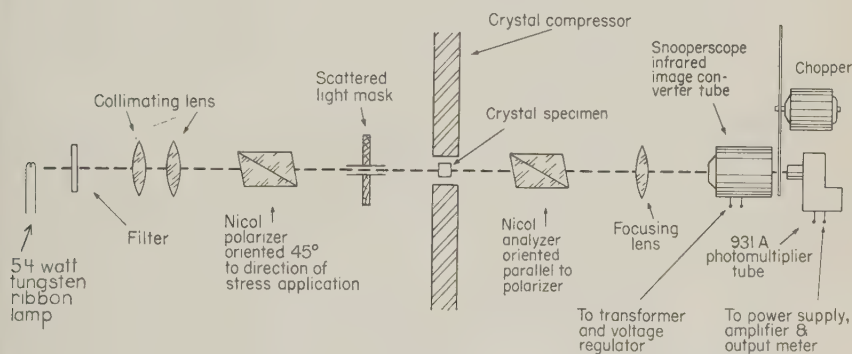


FIG. 1. A schematic diagram of the experimental apparatus used to determine the piezobirefringence constants of silicon.

cal, the latter being the direction of stress application to the crystal. A mask, provided with an aperture proper to the crystal dimensions, is placed between the polarizer and crystal specimen in order to eliminate all light except that passing through the specimen.

The apparatus used to apply stress to the silicon is a second class lever type of crystal compressor. The unit is similar to one previously described (2); however, the following modifications have been made: *a*) The pressure ram of the earlier model has been replaced by opposed vertical sections of $\frac{3}{4}$ inch diameter steel drill rod machined square at the ends and equipped with flat and parallel hardened steel tips. *b*) The cold-rolled steel plates formerly used as pressure ram guides have been replaced by a $1\frac{3}{8}$ inch thick normalized cast-iron block provided with a vertical guide hole for the drill rod plungers and an intersecting horizontal aperture for light transmission through the crystal. The pressure ram guide block is mounted vertically on a similar $1\frac{3}{8}$ inch thick cast iron base block. These improvements have been found to provide more easily reproducible conditions of stress distribution on crystal surfaces.

A nicol prism analyzer, oriented parallel to the polarizer, is placed on the opposite side of the crystal from the polarizer. A lens is used to focus the image of the crystal upon the cathode surface of a World War II war surplus British "snooperscope" infrared image converter tube, model CV-147. The brightness of the converted infrared image was measured by a 931A photomultiplier tube. The output signal from the photomultiplier tube was fed to a four-stage all-triode audio frequency amplifier tuned to 750 cps. The light chopper was placed between the infrared image converter and photomultiplier tubes in order to eliminate the effect of any image persistence by the active material of the converter tube. Changes in stress-induced retardation by the crystal specimen as a function of applied stress were read visually on a Triplet model 420-PL D.C. milliammeter. All electrical power used was drawn through a Sola CVH constant voltage transformer.

An infrared image converter tube was used in preference to a lead sulfide detector in order to permit visual inspection of the crystal specimen for optical defects and homogeneity of stress distribution. For some applications, however, the lead sulfide detector is a more advantageous instrument. The need for a phototube is then eliminated, the signal to noise ratio is better and power requirements are very simple.

Calibration of the "snooperscope" tube with respect to conversion range and band pass was carried out with a Leiss double prism-single pass spectrometer with a motor driven wavelength selector.* A zirconium point source lamp was used as a light source. The spectrometer itself was calibrated by means of a mercury vapor lamp spectrum. In order to establish the effective absorption cutoff of silicon and establish the conversion range of the image converter tube (operated at approximately 3000 volts A.C.), light from the spectrometer was transmitted through a 0.15 cm. thick polished silicon window. The converted light was observed with a 1P28 photomultiplier tube and recorded on a synchronized chart recorder.

In order to restrict the band pass, a 0.409 cm. thick Corning No. 5850 filter was inserted into the "snooperscope"-silicon system. Later, the No. 5850 filter was replaced by a distilled water filter (water thickness = 2.70 cm.). The observed transmission curves for (A) the Leiss spectrometer with the zirconium point light source, (B and C) the "snooperscope" image converter tube with a 0.15 cm. thick polished silicon window, (D) the distilled water filter, (E) the image converter tube with silicon window and water filter, (F) the Corning No. 5850 filter, and (G) the image converter tube with the silicon window and the Corning No. 5850 filter, are given for the wavelength region of 0.7–1.4 microns in Fig. 2.

* We wish to express our thanks to the University of Michigan Willow Run Laboratories, Infrared Section, and to J. Baker for operating the spectrometer.

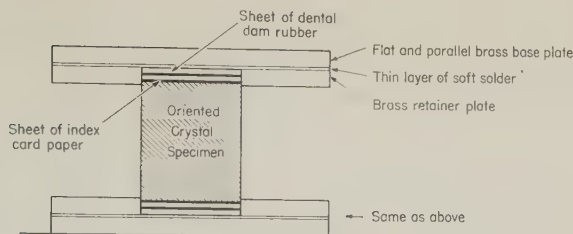


FIG. 2. A drawing of the "retained" resilient pressure pads used to provide good stress homogeneity on crystal surfaces.

An Eastman Kodak lead sulfide detector with a 1 cm.² window was used to measure "intensities" for curves A, D, and F, and a 1P28 photomultiplier tube was used for curves B, C, E, and G listed above. Transmission maxima were adjusted to a common value by means of the detector output signal amplifier. This procedure was maintained during piezobirefringence investigations.

The observed values of band pass and average wavelength at one-half "intensity" are given in Table 1. These values have been found to be reproducible to ± 0.005 micron. Therefore, data given in Table 1 are considered as correct to the second decimal place.

TABLE 1. BAND PASS AND AVERAGE WAVELENGTH (IN MICRONS) OF THE "SNOOPERSCOPE" INFRARED IMAGE CONVERTER TUBE (OPERATED AT 3000 VOLTS A.C. WITH FILTERS AS INDICATED)

	0.15 cm. thick polished silicon filter	0.15 cm. silicon + 2.70 cm. water filter	0.15 cm. silicon + Corning No. 5850 filter
Band pass at $\frac{1}{2}$ "intensity"	0.14	0.08	0.10
Av. wavelength at $\frac{1}{2}$ "intensity"	1.140	1.113	1.110

Briggs (6), Fan (7), and more recently, Salzberg and Villa (8) have determined the index of refraction of silicon in the wavelength region covered in this work. Because of the absorption cutoff, a significant dispersion exists in this part of the spectrum. For example, from the data of Briggs (6), the index of silicon at a wavelength of 1.05 microns is 3.565, whereas at 1.40 microns it is 3.499. Because of this appreciable dispersion, a small error in establishing the correct value of wavelength can cause an appreciable error in computing the values of the piezobirefringence constants. It will be shown later that the piezobirefringence constant is proportional to the wavelength and inversely proportional to the

cube of the index of refraction. At present, however, there is no theoretical explanation available by which refractive index dispersion may be related to possible piezobirefringent dispersion.

It has been shown (1, 2) that the application of a homogeneous stress to crystal surfaces is one of the most serious experimental problems encountered in stress-optical studies. In order to minimize this source of error, "retained" resilient pressure pads similar to those which Poindexter (1) developed and used successfully in his work on diamond were constructed. The pads are placed on the specimen pressure surfaces in order to minimize the effect of mechanical deficiencies in contact surfaces, and directional error in stress application. Each pad consists of a section of flat and parallel 1/32 inch thick brass plate tinned on one side with soft solder to a thickness of approximately 0.020 inch. Four similar but smaller pre-cut brass plates are then soldered to the base plate in such a way as to create a depression to fit the crystal specimen. For silicon and materials of similar thermal behavior, the finished oriented parallelepiped specimen itself may be used as a soldering template. Excess solder can be scraped from the depression by a sharp pointed jeweler's file or pocket knife. A thin sheet of dental dam rubber, cut to the proper size, is then inserted into the depression, followed by a sheet of index card paper of proper dimensions. The primary purpose of the paper is to act as a dam to prevent extrusion of the rubber between the crystal and brass retainer walls. A schematic diagram of the pressure pads mounted on a crystal is given in Fig. 3.

The retained Bridgman type of packing described above has been found to provide a very uniform distribution of stress on specimen surfaces up to pressures of approximately 700 kg./cm.². The homogeneity of stress distribution can be established qualitatively by visual inspection (infrared image converter tube) of the uniformity of polarized light transmission through the stressed crystal. Quantitative verification was carried out by measurement of the half wavelength positions of stress-induced light retardation.

SOURCES OF ERROR

The following sources of error are recognized in this study of the piezobirefringence in silicon:

- 1) Non-homogeneous stress distribution
- 2) Misalignment in polar orientation
- 3) Misalignment in crystal orientation
- 4) Spectral characteristics of the optical system
- 5) Non-monochromaticity of the light used
- 6) Error in the determination of the light wavelength
- 7) Error in the refractive index of silicon

- 8) Light beam non-parallelism
- 9) Fluctuations in line voltage
- 10) Drift and noise in the electronic circuit
- 11) Measurement of crystal dimensions

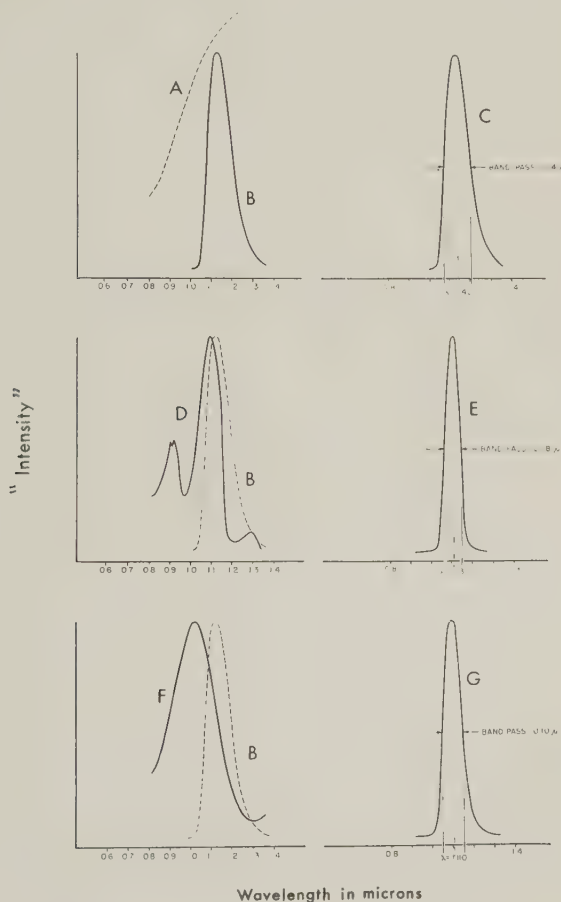


FIG. 3. Calibration curves for British World War II war surplus infrared image converter tubes, model CV-147, operated at 3000 volts A.C. with various filters. See text for details.

- 12) Inaccuracy in weight calibration
- 13) Inaccuracies in the calibration of the mechanical advantage of the lever arm
- 14) Frictional losses in the mechanical system
- 15) Personal error

The relative non-uniformity of stress distribution in this work has been found to be negligible. Values of $n\lambda/2$ intervals of stress-induced retardation for a given experiment are found to be reproducible to $\pm 1\%$. Independent experimental runs are also found to be reproducible to $\pm 1\%$. Errors in polar and crystal orientation are less than ± 15 minutes of arc, and therefore negligible. A thorough discussion on the effects of and corrections for poor stress distribution, polar misorientation and crystal misorientation in piezobirefringence investigation can be found in reference (9).

The determination of average wavelength, band pass and index of refraction of silicon are believed to be correct to $\pm 0.5\%$. The divergence of the light beam in air is less than 1 degree of arc, and therefore negligible. Measurements of crystal dimensions are correct to within ± 0.0005 cm. or approximately $\pm 0.2\%$. Weight calibration is correct to within $\pm 0.05\%$. The effect of fluctuations in line voltage was minimized by drawing all current through a Sola CVH constant voltage transformer.

All other sources of error listed above are variable and not amenable to quantitative evaluation. Their composite effect on the accuracy of the piezobirefringence constant is difficult to evaluate. However, the reported values are believed to be correct to within $\pm 2.5\%$.

EXPERIMENTAL RESULTS

Values for the piezobirefringence constants of crystalline materials may be calculated on the basis of the empirical mathematical stress-optical theory developed by F. Pockels (3, 4). Pockels' theorem may be expressed as

$$q = \frac{2h\lambda}{n_0^3 T d}.$$

For silicon, q represents the piezobirefringence constants ($(q_{1111} - q_{1122})$ and $2q_{1212}$); h = the amount of stress-induced retardation in units of wavelength; λ = the wavelength in air of the light expressed in centimeters; n_0 = the index of refraction for the unstressed material; T = the applied homogeneous stress expressed in dynes/cm.²; d = the path length through the crystal in centimeters. The wavelength of radiation used in this work has been measured as 1.11 microns with a band pass of 0.08 micron at $\frac{1}{2}$ "intensity" (silicon + water filters).

The experimentally measured value of the piezobirefringence constant ($q_{1111} - q_{1122}$) of silicon at 26° C. $\pm 1^\circ$ for a wavelength of 1.11 μ = -14.4×10^{-14} cm.²/dyne. The reported value of ($q_{1111} - q_{1122}$) has been obtained from the average of three independent determinations. The value of each determination, in turn, is obtained from the average of eight consecutive orders of $\lambda/2$ stress-induced retardation. The reproducibility between the

values of the consecutive orders of $\lambda/2$ retardation in each experimental run and between each of the three independent experiments both amount to $\pm 1.0\%$.

The experimentally determined value of piezobirefringence constant $2q_{1212}$ at $26^\circ \text{C.} \pm 1^\circ$ for radiation of 1.11μ wavelength has been found to be $-10.0 \times 10^{-14} \text{ cm.}^2/\text{dyne}$. This value represents the average of three independent determinations. Each determination in turn consists of the average obtained from five consecutive orders of $\lambda/2$ retardation. The reproducibility between the consecutive orders of $\lambda/2$ retardation and between each of the three independent determinations both amounted to $\pm 1.0\%$.

The piezobirefringent behavior of silicon at increasing values of stress is illustrated by Figs. 4 and 5. Figure 4 shows the linearity of the stress-optical relationship in silicon with an increasing homogeneous stress applied parallel to $X_1\bar{X}_1$ and light vibrating parallel to $X_1\bar{X}_1$ and traveling normal to $X_1\bar{X}_1$. Figure 5 illustrates the linearity of the stress-optical behavior of silicon for light vibrating parallel to X_{12} and traveling parallel to $X_3\bar{X}_3$ under an increasing stress directed along X_{12} .

Figure 6, a plot of "intensity" versus stress-induced retardation, illustrates the effect of a relatively wide band pass in the optical system of the experimental apparatus. The data were obtained by using unfiltered light from a 108 watt General Electric tungsten spiral filament lamp. Although the positions of the maxima and minima of transmitted intensity fall at uniform intervals, their respective amplitudes can be seen to decrease and increase in a nearly linear fashion. The fact that the positions of $n\lambda/2$ retardation occur at regular intervals indicates good stress distribution upon the pressure surfaces of the crystal. With poor stress distribution, the positions of $n\lambda/2$ retardation would be expected to occur at consecutively closer intervals due to an increasing non-homogeneity of the stress as the pressure is increased. A theoretical discussion of this phenomenon has been given (9).

The effect of decreasing the band pass has been experimentally observed by the insertion of a Corning No. 5850 filter (0.11μ band pass at $\frac{1}{2}I$) and a water cell filter (0.08μ band pass at $\frac{1}{2}I$), respectively, into the optical system. In both cases, the intensity at positions of $n\lambda/2$ retardation was observed to become more constant with a more restricted band pass. It appears, therefore, that the observed decrease in intensity contrast between increasing orders of $\lambda/2$ retardation as illustrated in Fig. 6 is due to an appreciable extent to the non-monochromaticity of the light used. The observed relationship appears to be analogous to the orders of interference colors commonly observed with the use of white visible light.

An attempt was made to determine the absolute values of the stress-

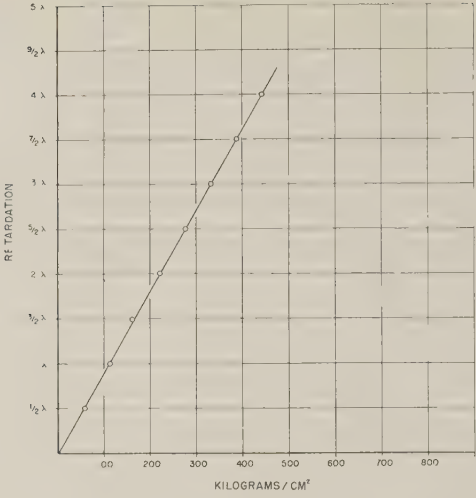


FIG. 4. The observed linearity of the stress-optical relationship in silicon described by the piezobirefringence constant ($q_{1111}-q_{1122}$).

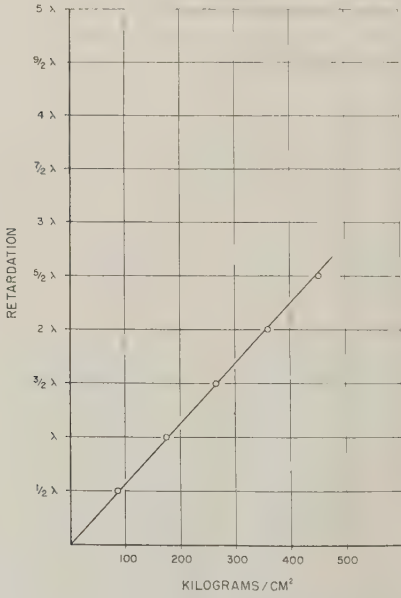


FIG. 5. The observed linearity of the stress-optical relationship in silicon described by the piezobirefringence constant $2q_{1212}$.

optical constants q_{1111} and q_{1122} . However, no quantitative success was achieved. The prism-deviation method described for SrTiO_3 (2) was used with the additional requirements of the infrared image converter tube. A description of the prism used is given in the section on Specimen Preparation.

The collimated light beam from a 0.025 cm. wide vertical slit was di-

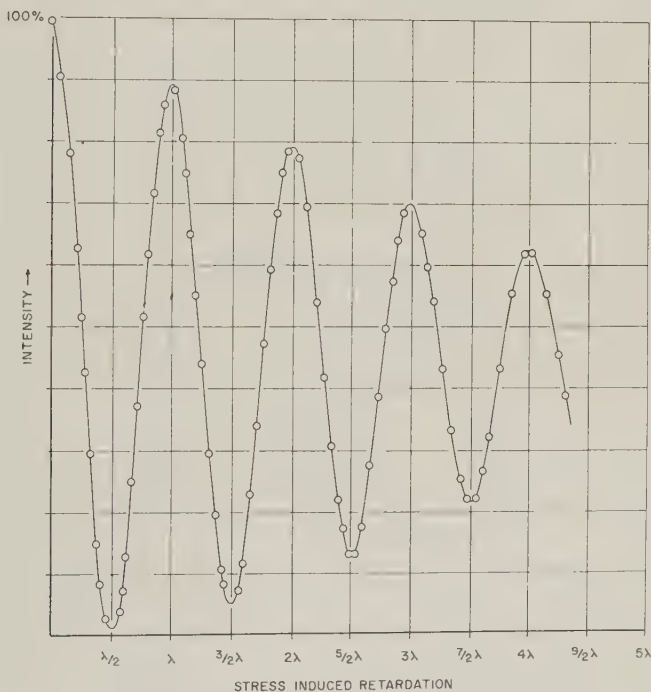


FIG. 6. The observed relationship between the relative transmission intensities and orders of stress-induced retardation for a uniformly stressed crystal when using poorly monochromatized infrared light.

rected to the prism at normal incidence. This orientation was established by observing the back reflection of the incident light ray. Stress was applied to the (100) right trapezium prism faces. A nicol polarizer, oriented with the vibration direction parallel to the direction of compression, was used in the attempt to evaluate q_{1111} . The vibration direction was oriented normal to the direction of stress for evaluation of q_{1122} .

A prism to detector distance of 3.25 meters was used and stresses up to approximately 600 kg./cm.² were applied to the crystal. This type of measurement is an extremely difficult one. The magnitude of the meas-

urements is approximately of the same order as the sensitivity of the measuring apparatus. A detailed discussion of the sources and magnitude of error involved can be found in reference (2). Additional difficulties encountered are the following: 1) wide band pass, 2) poor resolution of the image converter tube, 3) working with light that cannot be seen.

The experiment was repeated 15 times. Due to the serious inconsistencies in the results, no further attempts were made. However, the averaged values indicate the following approximate ratio of change in the index of refraction:

$$\Delta n_{11} : \Delta n_{22} \simeq (-)3 : (+)2.$$

The minus sign indicates the index of refraction parallel to the direction of stress decreases, whereas that normal to the direction of stress (positive) increases. Indications are, therefore, that silicon becomes a negative uniaxial crystal under a compression stress directed along [100]. If one tentatively accepts the above approximate ratios for Δn_{11} and Δn_{22} , indications of the values of the stress-optical constants q_{1111} and q_{1122} may be obtained from the stress-optical difference constant ($q_{1111} - q_{1122}$), namely, $q_{1111} \simeq -9 \times 10^{-14}$ cm.²/dyne and $q_{1122} \simeq 6 \times 10^{-14}$ cm.²/dyne.

DISCUSSION OF RESULTS

Since silicon and diamond both possess $m3m$ symmetry, have similar structures, and are both elemental materials, it should be of interest to compare their respective piezobirefringent behavior. It is desirable, however, that the following differences in physical properties and experimental conditions be tabulated first:

- 1) Diamond is transparent from the ultraviolet region of the spectrum to the near infrared.
- 2) Diamond possesses an absorption cutoff in the ultraviolet region of the spectrum at approximately 3000 Å (10, 11, 12).
- 3) Silicon is opaque to visible light.
- 4) The silicon absorption cutoff is at approximately 10500 Å.
- 5) The physical strength, therefore, bond strength in diamond, is many times that of silicon.
- 6) Comparable stress-optical work on diamond to date has been carried out at approximately 5400 Å, which is far removed from the absorption edge.
- 7) The present work on silicon has been carried out in the vicinity of the absorption cutoff, namely at 11100 Å.

The values of piezobirefringence constants observed by various workers on diamond are given in Table 2, along with the observed values for silicon reported in this paper.

As can be seen, the agreement of the values reported by different work-

ers on diamond is poor. The most recent work by Poindexter (1), however, is probably the most accurate.

As is to be expected, the numerical values of the respective constants of diamond and silicon differ. Of more pointed interest, however, is the piezobirefringent anisotropy, that is, the difference between $(q_{1111}-q_{1122})$ and q_{1212} . Although Ramachandran's values indicate a significant anisotropy, those reported by Grodzinski and Poindexter show only a small difference in value for the two piezobirefringence constants. It should be

TABLE 2. TABULATION OF PIEZOBIREFRINGENCE MEASUREMENTS OF DIAMOND BY DIFFERENT INVESTIGATORS AND OF SILICON

Material	Worker	Wavelength	$(q_{1111}-q_{1122})^*$	$2q_{1212}^*$
Diamond	Wertheim (13)	?	-3.3-	
Diamond	Ramachandran (14)	5461 Å	- 7.2	- 2.8
Diamond	Grodzinski (15) and Fisher	(Not reported)	- 3.85	- 3.78
Diamond	Poindexter (1)	5400 Å	- 3.04	- 2.98
Silicon	(This paper)	11100 Å	-14.4	-10.0

* Expressed in units of $\times 10^{-14}$ cm.²/dyne.

noted, however, that the magnitude of $(q_{1111}-q_{1122})$ reported by all workers on diamond (except Wertheim) is consistently greater than $2q_{1212}$. This agrees with the presently observed values for silicon. Silicon, however, shows a marked piezobirefringent anisotropy.

The fact that silicon has been studied very close to the absorption cut-off may be related to the observed difference in anisotropy between diamond and silicon. Most past work on diamond has been carried out at an average wavelength of 5400 Å. Poindexter has investigated the piezobirefringent dispersion of $2q_{1212}$ as a function of wavelength from 4400 Å to 7700 Å. His results show a slight dispersion amounting to approximately 4% in this wavelength range. No study has been made on the dispersion of $(q_{1111}-q_{1122})$.

Diamond may possess a piezobirefringent anisotropy at the absorption edge in the ultraviolet region of the spectrum which is comparable to that observed in silicon at 1.11 μ . The wavelength relationship of both piezobirefringence constants of diamond should be investigated to approximately 3000 Å. Similarly, silicon should be studied further into the infrared.

CONCLUSIONS

The following values have been determined for the piezobirefringence

constants of "high purity" silicon at a wavelength of 1.11μ and a temperature of $26^\circ \text{C.} \pm 1^\circ$:

$$(q_{1111} - q_{1122}) = -14.4 \times 10^{-14} \text{ cm.}^2/\text{dyne}$$

$$2q_{1212} = -10.0 \times 10^{-14} \text{ cm.}^2/\text{dyne}$$

The linearity of the stress-induced retardation described by both constants has been established up to pressures of approximately 450 kg./cm.² The observed significant piezobirefringent anisotropy of silicon in the vicinity of its absorption cutoff indicates the possibility of greater anisotropy for diamond at its absorption cutoff ($\sim 3000 \text{ \AA}$). Qualitative observations indicate that silicon becomes a uniaxial negative crystal under a directional stress parallel to [100].

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REFERENCES

1. POINDEXTER, E. H.: *Am. Mineral.*, **40**, 1135 (1955).
2. GIARDINI, A. A.: *J. Opt. Soc. Am.*, **47**, No. 8 (1957).
3. POCKELS, F.: *Weid. Ann. Phys.*, **37**, 151 (1889).
4. ———: *Lehrbuch der Kristalloptik*, Leipzig-Berlin (1906).
5. GIARDINI, A. A.: *Am. Mineral.*, **43**, 370 (1958).
6. BRIGGS, H. B.: *Phys. Rev.*, **77**, 287 (1950).
7. FAN, H. Y.: *Phys. Soc. Lond.*, **19**, 123 (1956).
8. SALZBERG, C. D., AND VILLA, J. J.: *J. Opt. Soc. Am.*, **47**, No. 3, 244 (1957).
9. GIARDINI, A. A.: Thesis, Univ. of Mich. (1956).
10. PETER, F.: *Zeit f. Phys.*, **15**, 358 (1923).
11. ROBERTSON, FOX, AND MARTIN: *Phil. Trans. Roy. Soc.*, **232A**, 482 (1934).
12. RAMANATHAN, K. G.: *Proc. Ind. Acad. Sci.*, **24**, 130, 137 (1946).
13. WERTHEIM, G.: (Note: The writer has not been able to obtain the original references but quotes E. Coker and L. Filon, *A Treatise on Photoelasticity*, Cambridge Univ. Press, 1931.)
14. RAMACHANDRAN, G.: *Proc. Ind. Acad. Sci.*, **32**, 171 (1950).
15. GRODZINSKI, P.: *Brit. J. App. Phys.*, **1**, 241 (1950).

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TWINNING IN DIAMOND-TYPE STRUCTURES: A PROPOSED BOUNDARY-STRUCTURE MODEL*

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ABSTRACT

Lateral twin boundaries (twin plane and boundary plane not coincident), second-order twin joins (boundaries between individuals related by two non-parallel stages of twinning), and probable third-order twin joins have been observed in silicon. Their directions are restricted to rows of sites in a coincidence site superlattice (net of positions common to both individuals of the twin). Using (110)-projected coincidence nets, seven *permissible* (hhl) boundaries can be derived (four first-order and three second-order); these have high coincidence site density and their trans-boundary structure is "restorable" to a considerable degree if the discontinuity zig-zags, or oscillates between two (or three) simple crystallographic directions in each case. By using a zig-zag discontinuity as a "restoration" mechanism, trans-boundary deviations from undistorted bonding are minimized, and a preferred growth along these directions is to be expected. The seven proposed boundaries are

<i>First-Order</i>	<i>Second-Order</i>
$\{115\}-\{111\}$	$\{221\}-\{221\}$
$\{112\}-\{112\}$	$\{115\}-\{111\}$
$\{001\}-\{221\}$	$\{114\}-\{114\}$
$\{110\}-\{114\}$	

Constructions are presented showing the proposed, ideal, detailed structure for the seven boundaries. Six of these seven have been observed experimentally in the same silicon specimen. *No other* first- or second-order discontinuities were found.

Grain boundary energy relationships are discussed; reference is made to implications on semiconductor properties.

INTRODUCTION

Interest has been focussed recently on the crystallography of diamond-type materials, especially silicon and germanium, owing to their use in semiconductor devices. The proper functioning of such devices depends, in part, upon the crystalline perfection of the material involved, and to this end, the defect structure of diamond-type crystals has come under close scrutiny. Twinning, of course, is a defect, and as such it is a possible deterrent to structure-sensitive electrical properties (1), e.g., lifetime of minority carriers and carrier mobility.

As discussed by Slawson (2), diamond crystals are predisposed to twinning. As expected, silicon and germanium, both of which are isomorphous with diamond, also show high degrees of twinning. Further, diamond and silicon have been shown to exhibit more complex, high-order twinning (2) (3) (4), a feature which undoubtedly is also displayed by ger-

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manium. Simple first-order twinning, where twin plane (invariably (111) for these materials) and composition plane are coincident, gives rise to only a slight structure discontinuity. Structure-sensitive electrical properties are expected to be essentially unaffected. Most workers agree that even lifetime of minority carriers, the most structure-sensitive electrical property, is not altered in such a case (5). It might be expected that multiple parallel twinning of this type would have an effect on lifetime; experimental data, however, are not available. It has been shown by the use of an infrared image tube that multiple parallel twinning gives rise to an observable birefringence, probably deriving from the cumulative effect of the anisotropic (hexagonal) lamellae introduced by the twinning operations (6).

A structure discontinuity of somewhat higher degree would be expected in the case of first-order twinning if the twin plane and composition plane are not coincident. Such *lateral* (also referred to as "semi-coherent," "noncoherent," and "incoherent") twin boundaries have been discussed by Ellis and Treuting (7) for cubic crystals and reported in several materials. They have been observed in silicon during the present study and are described herein. Lateral twin boundaries, since they entail a greater deviation from undistorted bonding than those in which twin plane and composition plane are coincident, are expected to have a somewhat greater effect upon structure-sensitive electrical properties; no direct measurements, however, are available.

Other structure discontinuities are generated by high-order twinning. A diamond-type crystal, I, twins and the resultant individual, II, twins again (non-parallel) to generate a third crystal, III. Should I and III then become contiguous, the boundary along which contact is made is termed a second-order twin join (4). Similarly, should the individuals making contact be related by three stages of non-parallel twinning, a third-order join is developed. As the order of the particular twin join increases, deviation from undistorted bonding becomes greater, and the effect on structure-sensitive electrical properties is expected to increase. Finally, after four stages of twinning, there are no longer any lattice sites common to both individuals (see discussion below), and the discontinuity probably approaches that of a common grain boundary having high energy. High-energy grain boundaries are of practical importance for certain semiconductor device applications (8).

Grain boundary energy, as described by Read (9), is comprised of two types: the energy of atomic disorder and the energy of elastic deformation. Read and Shockley (10) have correlated grain boundary energy with the angle of misfit between the two crystals. Expressed in terms of bonding, it would seem that as the specific deviations from undistorted

bonding increase, the energy of the particular grain boundary increases. In other words, the greater the degree to which the trans-boundary structure can be "restored" to the undistorted state, the lower the associated energy.

A general grain boundary has five degrees of freedom. In the case of a discontinuity derived by twinning, three of these degrees of freedom are established; the two remaining are associated with the orientation of the surface along which the two individuals make contact. To determine the possible orientations of such a surface, consider the "interpenetrated" lattices of two individuals twinned with respect to each other. Certain atomic sites are common to both structures, and these sites form a net, which Ellis and Treuting have referred to as a coincidence site superlattice (7). First-order twinning has associated with it a specific coincidence superlattice, which differs from those accompanying second- and third-order twinning. With fourth- and presumably higher-order twinning of a diamond-type structure, there are no lattice points common to both individuals and therefore no coincidence site superlattice exists. A given twin boundary will tend to contain lattice sites common to both individuals, that is to orient itself along rows of sites in the coincidence net. In so doing, it would tend to minimize deviations from an undistorted structural array and thus lower its associated energy. Lattice site directions in the coincidence site superlattice, then, represent cusps or minima in the curve relating grain boundary energy and boundary direction.

The coincidence net, of course, is three-dimensional. The problem can be simplified with a two-dimensional approach. First-order twinning in the diamond structure can be interpreted geometrically as a rotation about $[110]$ of $70^{\circ}32'$. Further, second- and third-order twinings can be considered as rotations about $[110]$ of $38^{\circ}57'$ and $31^{\circ}35'$, respectively. Superposed (110) projections, rotated by the proper amount, give two-dimensional coincidence site superlattices which are constant-projecting along the third direction, $[110]$. Restriction to such a two-dimensional net, in effect, eliminates one of the two degrees of freedom associated with the boundary surface. It is sufficient, nevertheless, to describe the model. Actually, in practice, one of these two degrees of freedom is somewhat controlled during growth of the crystals: the two most widely used methods for growing single crystals of silicon today, the Czochralski technique (pulling from a melt) (11) and the floating zone method (moving a molten zone vertically through an ingot) (12), both impart a strong unidirectional temperature gradient to the crystal, and it has been shown that twin boundaries in silicon tend to follow the temperature gradient (13).

Examination of superposed (110) projections (first- and second-order

twinning) reveals that only in case of the usual first-order twinning, with twin plane and composition plane coincident, can a "restorable" (cf. section on *First-Order Twinning*) straight line boundary be drawn.* As is well known, the restoration in this case is nearly complete, involving deviations commencing with the third coordination sphere. In the case of lateral twin boundaries and second-order twin joins, "restorable" boundaries can be attained if a type of oscillating, or zig-zag discontinuity

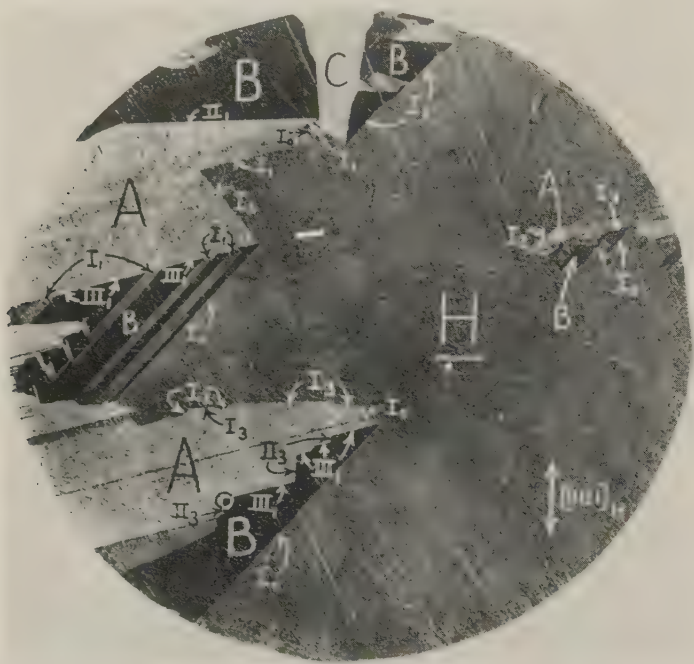


FIG. 1. Silicon crystal section, viewed approximately along $[110]$, showing host, twins, and observed boundaries; see text for explanation of symbols. $9\times$.

is employed. The resultant directions of such zig-zag discontinuities follow rows of lattice sites in the respective coincidence net.

EXPERIMENTAL RESULTS

Figure 1 shows an etched section of a silicon crystal. The crystal was grown by pulling from a melt along $[100]$; the section is viewed approximately along $[110]$. The dark gray area (bulk of the section) is the host crystal, H; the light gray and black areas are mainly first-order twins

* Refer to discussion of the $\{112\}-\{112\}$ lateral twin boundary (*First-Order Twinning* section) for qualification of this statement.

with respect to the host. Specifically, the light gray regions designated A are twinned on $(\bar{1}11)$ of the host; the black areas, labelled B, are twinned on (111) ; the light gray area designated C is twinned on (111) . The host, A, and B have a common (110) approximately in the plane of the figure and are amenable to the two-dimensional treatment using superposed (110) projections. The discussion will therefore be limited to these orientations.

TABLE 1. PROPOSED AND OBSERVED $(h\bar{h}l)$ BOUNDARIES

	Proposed from Model	Experimentally Observed	Figure 1 Designation
First Order	$\{115\}-\{111\}$	$\{115\}-\{111\}$	I ₁
	$\{112\}-\{112\}$	$\{112\}-\{112\}$	I ₂
	$\{001\}-\{221\}$	$\{001\}-\{221\}$	I ₃
	$\{110\}-\{114\}$	$\{110\}-\{114\}$	I ₄
Second Order	$\{221\}-\{221\}$	$\{221\}-\{221\}$	II ₁
	$\{115\}-\{111\}$	not found	—
	$\{114\}-\{114\}$	$\{114\}-\{114\}$	II ₃

The twinning relationships among the crystallographic areas of Fig. 1, as well as the directions of the various boundaries, were established by x-ray diffraction, using the back-reflection Laue method. For consistency with the two-dimensional treatment used herein, the relatively few boundaries oblique to the plane of the figure, i.e., other than $(h\bar{h}l)$, were not considered. In addition to the normal first-order twinning case, wherein twin plane and composition plane are coincident, four lateral twin boundaries of the type $(h\bar{h}l)$, i.e., containing $[110]$, were found. Indexed with respect to the axes of both host and twin, they are $\{115\}-\{111\}$, $\{112\}-\{112\}$, $\{001\}-\{221\}$, and $\{110\}-\{114\}$. These lateral twin boundaries are designated I₁, I₂, I₃, and I₄, respectively, in Fig. 1; the normal case is designated I₀. Examination of boundaries between individuals related by two orders of twinning showed two $(h\bar{h}l)$ second-order twin joins, $\{221\}-\{221\}$ and $\{114\}-\{114\}$. These are designated II₁ and II₃, respectively, in Fig. 1. The observed boundaries for first- and second-order twinning are listed in Table 1 and compared with those derived by purely theoretical considerations using the proposed model (see subsequent sections for derivation and discussion); the appropriate designations for Fig. 1 are also listed.

No other $(h\bar{h}l)$ first-order lateral twin boundaries or second-order twin joins were experimentally observed in the present study. One additional set of boundaries, however, was found (cf. III₁, Fig. 1). Although these

seemed at first to be second-order twin joins having a direction contrary to the proposed model, examination under high magnification showed that they were probably higher-order twin joins. These boundaries are discussed in detail in the section on *Third-Order Twinning*.

FIRST-ORDER TWINNING

Figure 2 shows the coincidence site superlattice for first-order twinning derived by rotating superposed (110) projections by $70^{\circ}32'$ about [110]. Only sites common to both individuals are shown; intervening

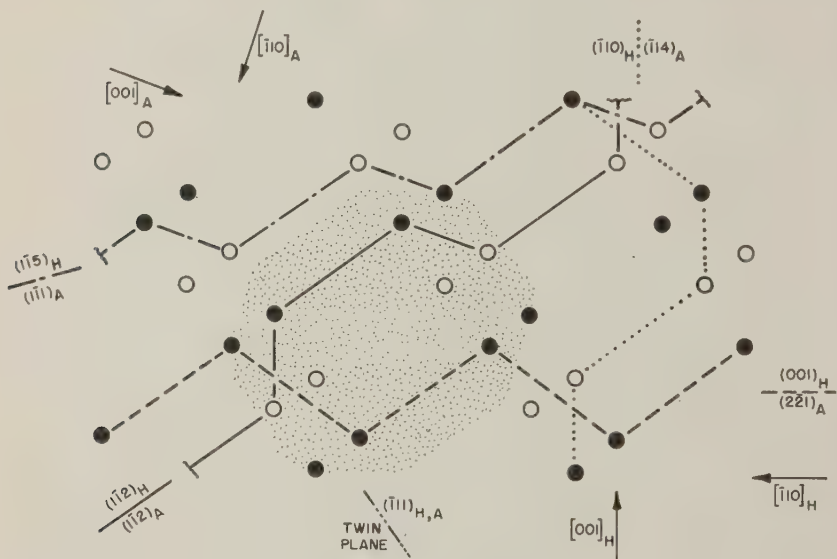


FIG. 2. (110)-projected coincidence site superlattice for first-order twinning, showing traces of proposed $(h\bar{h}l)$ lateral twin boundaries.

atomic positions of the "interpenetrated" twin pair have been omitted. Crystallographic directions of the host individual, H, and individual A, generated by twinning on $(\bar{1}11)$, are noted for correlation with subsequent diagrams. Solid symbols represent sites in the plane of the drawing; open symbols refer to sites $\sqrt{2} a_0/4$ above (or below) the plane of the figure.

As stated previously, a boundary will tend to orient itself along rows of sites in the coincidence net, in order to minimize its associated energy. It would seem, also, that the resultant discontinuity should be such that its trans-boundary structure can be rebuilt, or *restored* to a state approaching normalcy. The proposed boundary-structure model is based on the

requirements of (a) high coincidence site density and (b) a considerable degree of trans-boundary structural restoration. These conditions can be satisfied simultaneously if the discontinuity zig-zags between restorable, inter-site segments in the coincidence net. What restorable segments are available to such a zig-zag discontinuity?

The stippled area of Fig. 2 is reproduced in Fig. 3a to show the complete, "interpenetrated" structures. From coincidence site 1, the boundary can proceed along segments to coincidence positions 2, 3, 4, 5, 6, or 7. Excepting symmetrically equivalent segments, other directions are

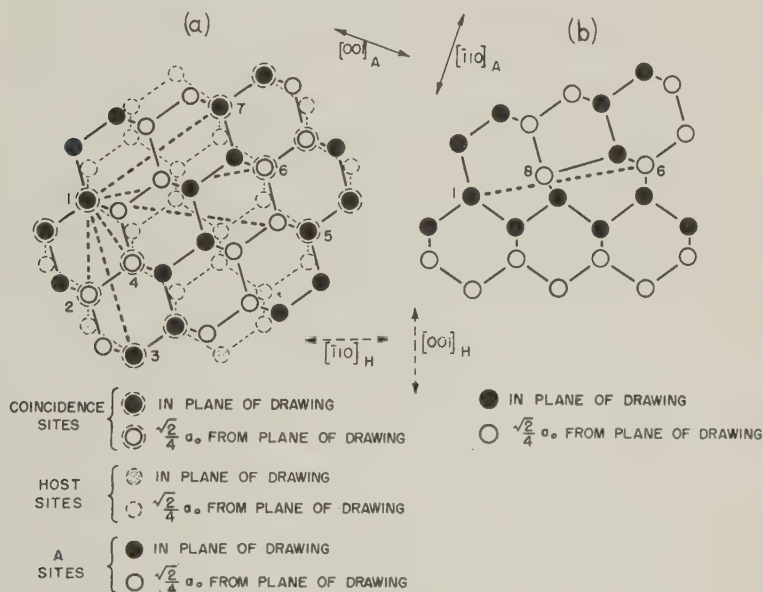


FIG. 3. (a) Detail of stippled area in Fig. 2, showing complete "interpenetrated" structures and possible boundary segments. (b) A reconstructed 1-6 vector, exemplifying a "non-restorable" boundary segment.

eliminated owing to requirement (a) above, i.e., higher coincidence site density. Do the six available segments permit structural restoration when used in actual boundaries? The discontinuity illustrated in Fig. 5 (see ahead) uses segments 1-2 (short) and 1-7 (long). A considerable degree of structural restoration has been achieved; these are "restorable" segments. The boundary in Fig. 6 uses a segment symmetrically equivalent to 1-3 as its NW-SE component; this is also a restorable segment. On the other hand, 1-5 and 1-6 are "non-restorable" segments. This is illustrated in Fig. 3b, using 1-6. Substantial deviations from normal

bonding result (note position 8); the trans-boundary structure cannot be suitably restored. Use of the 1-4 segment, or longer segments having the same direction, results in a boundary which degenerates either to the usual $\{111\}$ - $\{111\}$ twin boundary or to a discontinuity employing the restorable segments mentioned above.

Using simple combinations of the three established restorable segments, four ($h\bar{h}l$) zig-zag discontinuities were found representing permissible lateral twin boundaries.* Indexed with respect to the axes of both individuals, the resultant directions of these boundaries lie along $(115)_H$ -

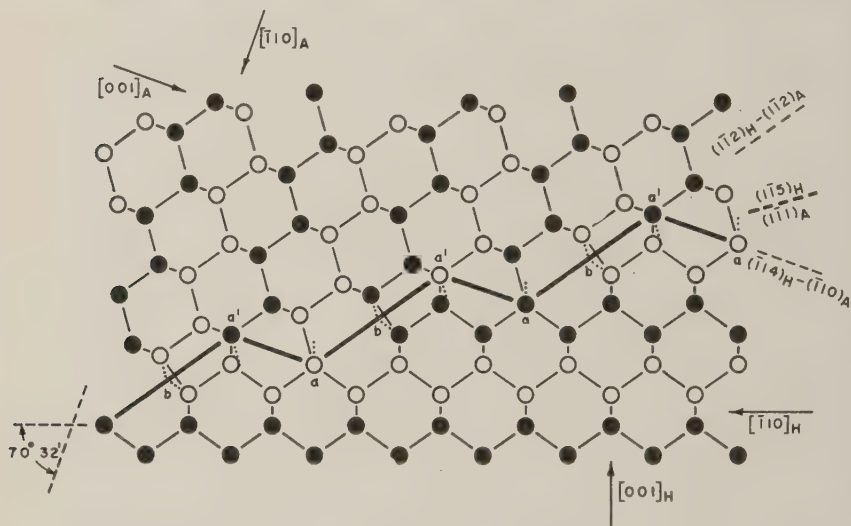


FIG. 4. $\{115\}$ - $\{111\}$ lateral twin boundary; see text for symbol explanation.

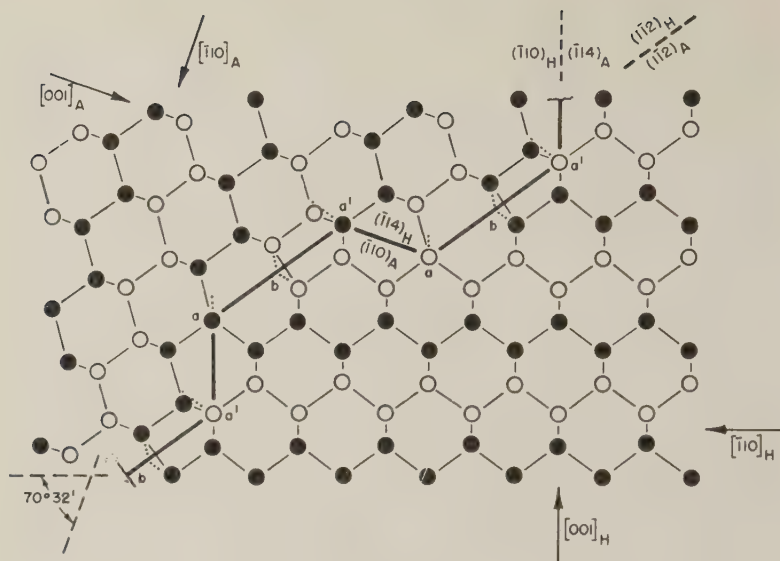
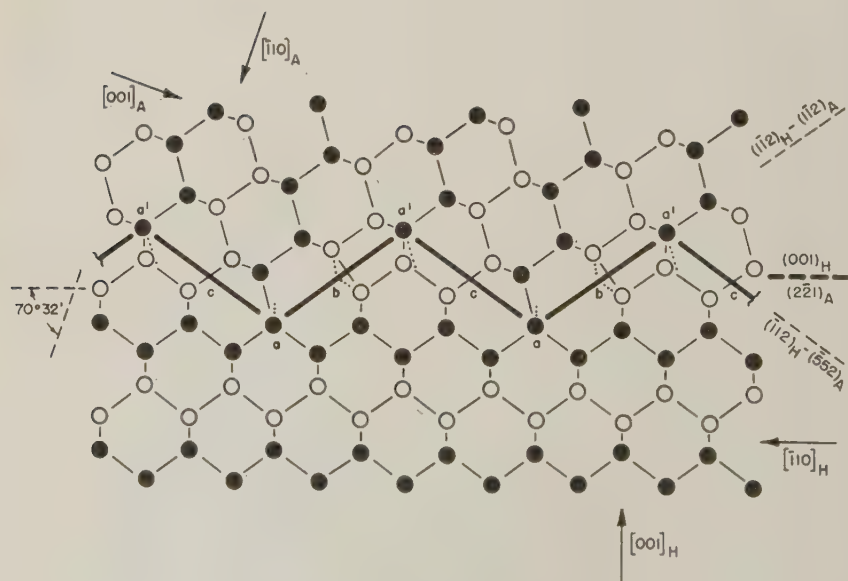
$(1\bar{1}1)_A$, $(112)_H$ -($1\bar{1}2$)_A, $(001)_H$ -(221)_A, and $(\bar{1}10)_H$ -(114)_A. Their relationship to the coincidence net is shown in Fig. 2. With the exception of more complex boundaries using combinations of these four, no other permissible ($h\bar{h}l$) lateral twin boundaries could be found which satisfied the requirements of the model.

Figures 4, 5, 6, and 7 show the proposed, ideal, detailed structure of the four restored lateral twin boundaries. The zig-zag discontinuity having a resultant direction along $(1\bar{1}5)$ of the host and $(1\bar{1}1)$ of individual A is shown in Fig. 4. The host structure, below the discontinuity, is related to that of A, above the boundary, by a rotation of $70^\circ 32'$ about a

* A three dimensional analysis would include a permissible $\{110\}$ - $\{110\}$ boundary (in the plane of Fig. 2); such a boundary has been observed in copper (14) and indium antimonide (15). Also, Churchman, Geach, and Winton (16) mention $\{123\}$ - $\{321\}$ and $\{201\}$ - $\{021\}$ "semi-coherent" boundaries for first-order twinning in the diamond structure.

normal to the figure, $[110]$. The proposed discontinuity oscillates between segments having directions along $(\bar{1}\bar{1}2)_H-(\bar{1}\bar{1}2)_A$ and $(\bar{1}14)_H-(\bar{1}10)_A$ (segment types 1-7 and 1-2, respectively, of Fig. 3a). As shown in the construction, the trans-boundary structure is restorable to a considerable degree. Undistorted atomic configuration leads to a six-sided array, as seen projected along $[110]$. Along unit length (two adjacent segments), the proposed discontinuity offers, instead, an altered six-sided figure followed by a seven- and a five-sided array. Of greater interest in examining deviations from an undistorted atomic configuration is the direction and/or length of specific bonds along the discontinuity. At atomic positions where such changes have taken place, the former bond directions are indicated by dotted lines in the figure. At points designated a and a' , the bond has been rotated respectively into and out of the plane of the figure by $57^\circ 1'$. At b two bonds have been combined to one, the resultant being approximately 6% shorter than normal; each original bond has been rotated $19^\circ 28'$ in the plane of the figure. Neglecting the shortened bond, the atoms on either side of position b still have four nearest neighbors. Atoms at a and a' , however, have changed in this respect. Specifically, the a positions now require only three nearest neighbors, while the a' sites require five nearest neighbors. The a and a' positions in Fig. 4 are third nearest neighbors; the paired separation is $0.829a_0$ or 1.9 times the usual bond length ($0.433a_0$). The proximity of these abnormally coordinated sites allows for an adjustment of the structure to alleviate the condition. In other words, there should be a tendency for one of the bonds directed at a' to be redirected toward a . Additional, more subtle adjustments of the structures on either side of the discontinuity should be expected in order to accommodate the proposed boundary changes. A considerable degree of restoration, nevertheless, has been achieved, which effectively lowers the energy associated with the discontinuity. This boundary energy is higher than would have been the case if twin plane and composition plane were coincident, but not as high as that associated with a common grain boundary, where restoration is presumably at a minimum. See Table 1 and Fig. 1 for comparison with experimental results.

The second lateral twin boundary, that having a resultant direction along (112) of the host and (112) of individual A, is shown in Fig. 5. The relative orientations of host and A are precisely the same here as in the previous construction. The discontinuity oscillates, as shown, among segments having directions along $(\bar{1}14)_H-(\bar{1}10)_A$, $(\bar{1}\bar{1}2)_H-(112)_A$, and $(110)_H-(114)_A$ (segment types 1-2, 1-7, and 1-2, respectively, of Fig. 3a). Along unit length of the discontinuity, i.e., two adjacent segments, the projected atomic configuration shows an altered six-, a seven-, and a

FIG. 5. $\{112\}$ - $\{112\}$ lateral twin boundary.FIG. 6. $\{001\}$ - $\{221\}$ lateral twin boundary.

five-sided array, in this respect being the same as the $\{115\}$ - $\{111\}$ discontinuity. In fact, the specific bonding changes indicated at positions a , a' , and b are the same as at the similarly designated positions in Fig. 4.* Comparison between the $\{115\}$ - $\{111\}$ and $\{112\}$ - $\{112\}$ boundaries reveals that they differ only with respect to the direction reversals shown by the latter. See Table 1 and Fig. 1 for comparison with experimental results; $\{112\}$ - $\{112\}$ boundaries have also been observed in silicon by Salkovitz and von Batchelder (17).

Actually, a straight line discontinuity can be constructed as an alternative for the $\{112\}$ - $\{112\}$ lateral twin boundary. In this case, however, the sites requiring three and five nearest neighbors are already connected by a bond in the plane of the discontinuity. The actual equilibrium position for the boundary is most probably between the two extremes, i.e., between a straight line discontinuity and that presented in Fig. 5.

The lateral twin boundary having a resultant direction along (001) of the host and ($\bar{2}21$) of individual A is shown in Fig. 6. The relative orientations of the two individuals are again the same as in the two cases just discussed. The discontinuity oscillates between segments having directions along $(1\bar{1}2)_H$ - $(1\bar{1}2)_A$ and $(\bar{1}12)_H$ - $(\bar{5}52)_A$ (segment types 1-7 and 1-3, respectively, of Fig. 3a). Two adjacent boundary segments show projected atomic configurations having six, six (both altered), seven, and five sides. Again, specific deviations in bonding noted at positions a , a' , and b are the same as in the foregoing two constructions. At c the bond is altered only for third and higher coordinations, i.e., the normal first-order twinning relationship. In the present construction, positions a and a' , which require three and five nearest neighbors respectively, are separated by $1.479a_0$ or 3.4 times the usual bond length. This distance is considerably greater than the separation found in the case of the first two lateral twin boundaries ($0.829a_0$). Accordingly, the structural adjustments necessary to accommodate the specified abnormalities are not as easily accomplished. See Table 1 and Fig. 1 for comparison with experimental results.

The fourth lateral twin boundary for first-order twinning is shown in Fig. 7; it has a resultant direction along $(\bar{1}10)$ of the host and $(\bar{1}14)$ of individual A. The boundary oscillates among segments having directions along $(1\bar{1}2)_H$ - $(1\bar{1}2)_A$, $(\bar{1}10)_H$ - $(114)_A$, and $(112)_H$ - $(552)_A$ (segment types 1-7, 1-2, and 1-3, respectively, of Fig. 3a). The projected atomic configurations along three successive boundary segments show four altered six-sided arrays followed by two having seven and five sides. The specific

* Ellis and Treuting (7) noted that in the case of a $\{112\}$ - $\{112\}$ lateral twin boundary in the diamond structure, atoms on the coincidence plane have alternately three and five nearest neighbors.

bonding deviations noted at a , a' , b , and c are as previously indicated. The abnormally coordinated sites a and a' , although paired in their distribution along the discontinuity, are separated by 3.4 times the usual bond length. There are less such sites along unit length of the (110) -projected boundary than in the three constructions described above. See Table 1 and Fig. 1 for comparison with experimental results.

From a theoretical point of view, the four discontinuities described

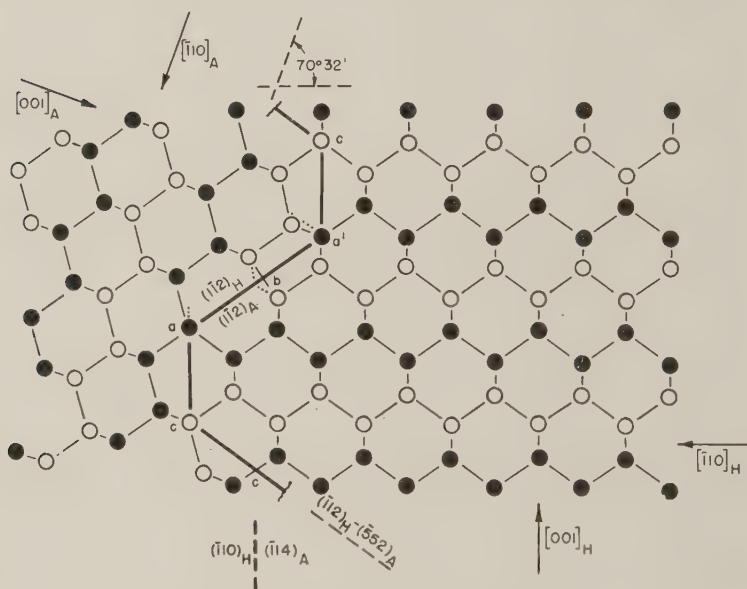


FIG. 7. $\{110\}$ - $\{114\}$ lateral twin boundary.

above are the only simple, $(h\bar{h}l)$ lateral twin boundaries susceptible to a considerable degree of structural restoration and having high coincidence site density. One might propose more complicated boundaries based upon combinations of these to varying degrees, but this seems impractical. It appears significant that, among the clearly delineated $(h\bar{h}l)$ lateral twin boundaries found in the specimen (Fig. 1), the $\{115\}$ - $\{111\}$, $\{112\}$ - $\{112\}$, $\{001\}$ - $\{221\}$, and $\{110\}$ - $\{114\}$ discontinuities, and *only these*, were observed. Such boundaries, then, have a strong tendency to orient themselves along rows of lattice sites in the coincidence site superlattice for first-order twinning. The zig-zag discontinuity is proposed as a mechanism of restoration, whereby the necessary trans-boundary deviations from an undistorted atomic configuration are minimized and the energy associated with the discontinuity is effectively reduced.

SECOND-ORDER TWINNING

The coincidence site superlattice for second-order twinning is shown in Fig. 8. It was derived by rotating superposed (110) projections by $38^\circ 57'$ around $[110]$. Crystallographic directions are indicated for individual A, generated by twinning on $(\bar{1}11)$ of the host, and for individual B, derived by twinning on $(\bar{1}\bar{1}1)$ of the host. Comparison with Fig. 2 shows that the coincidence net for second-order twinning has a consider-

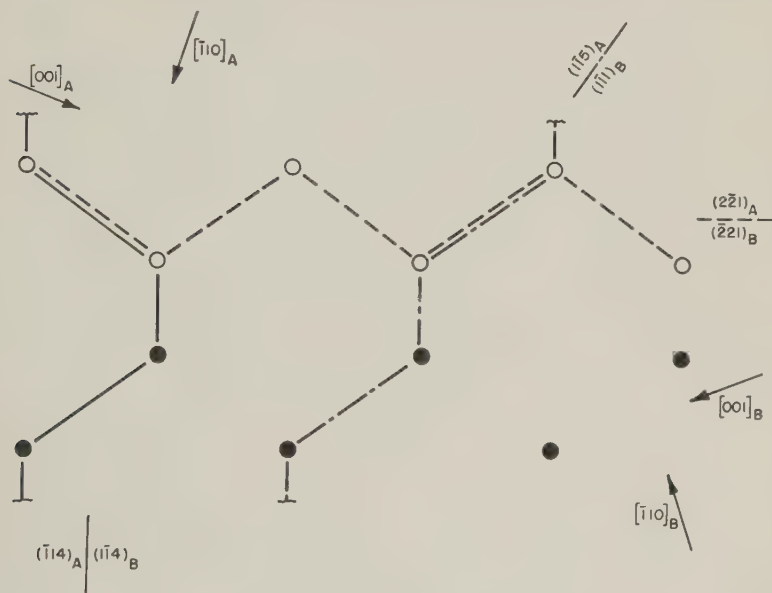


FIG. 8. (110)-projected coincidence site superlattice for second-order twinning, showing traces of proposed $(h\bar{h}l)$ second-order twin joins.

ably lower site density. Using the same requirements as were applied for first-order twinning, it is found that there are but two restorable segments: $(\bar{1}14)_A$ - $(1\bar{1}4)_B$ and $(1\bar{1}2)_A$ - $(2\bar{2}1)_B$ (or symmetrically equivalent $(2\bar{2}1)_A$ - $(112)_B$). Simple combinations of these yield three $(h\bar{h}l)$, restorable, zig-zag discontinuities representing permissible second-order twin joins.* Indexed with respect to the axes of both individuals, these have resultant directions along $(2\bar{2}1)_A$ - $(221)_B$, $(1\bar{1}5)_A$ - $(1\bar{1}1)_B$, and $(114)_A$ - $(114)_B$. Their relation to the second-order coincidence net is shown in Fig. 8. No other permissible boundaries, excepting combinations of these three, could be derived offering discontinuities susceptible to a con-

* A three-dimensional analysis would again include a permissible $\{110\}$ - $\{110\}$ boundary (in the plane of Fig. 8). Dunn, Daniels, and Bolton (18) mention such a boundary for Si-Fe.

siderable degree of trans-boundary restoration and having high coincidence site density.

The second-order twin join having a resultant direction along $(\bar{2}\bar{2}1)$ of individual A and $(\bar{2}21)$ of individual B is shown in Fig. 9. The structure of A, above the discontinuity, is related to that of B, below the boundary, by a rotation of $38^\circ 57'$ about a normal to the figure, $[110]$. The discon-

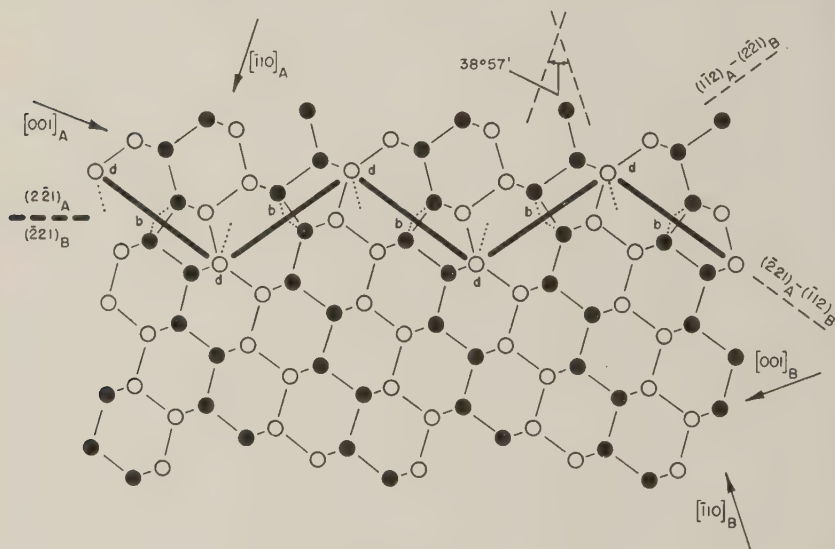


FIG. 9. $\{221\}$ - $\{221\}$ second-order twin join; see text for symbol explanation.

tinuity oscillates between segments having directions along $(1\bar{1}2)_A$ - $(\bar{2}\bar{2}1)_B$ and $(\bar{2}21)_A$ - $(\bar{1}12)_B$. The projected atomic configurations along two adjacent segments of the proposed discontinuity show consecutive arrays having seven, five, seven, and five sides. At positions designated b in Fig. 9, two bonds have been rotated $19^\circ 28'$ in the plane of the construction and combined to one; the resultant is 6% shorter than the normal bond. This particular deviation from undistorted bonding is present in all seven discontinuities referred to herein, i.e., in the four lateral twin boundaries discussed heretofore and in the three second-order twin joins presently being treated. At points d , the bond has been rotated alternately clockwise and counterclockwise by $31^\circ 35'$ in the plane of the figure. Neglecting the shortened bond at b , atoms along the discontinuity maintain four nearest neighbors. This is in contrast with the four first-order boundaries, where atoms along the coincidence plane had alternately three and five nearest neighbors. See Table 1 and Fig. 1 for comparison with experimental results. The $\{221\}$ - $\{221\}$ second-order twin

join has previously been encountered in silicon (cf. Fig. 4 of reference 4).

The second-order twin join shown in Fig. 10 has a resultant direction along $(1\bar{1}5)$ of individual A and $(\bar{1}11)$ of individual B. The relation between A and B is the same as in the previous construction. The discontinuity oscillates between segments having directions along $(1\bar{1}2)_A$ - $(2\bar{2}1)_B$ and $(\bar{1}14)_A$ - $(114)_B$. Adjacent segments show projected atomic configura-

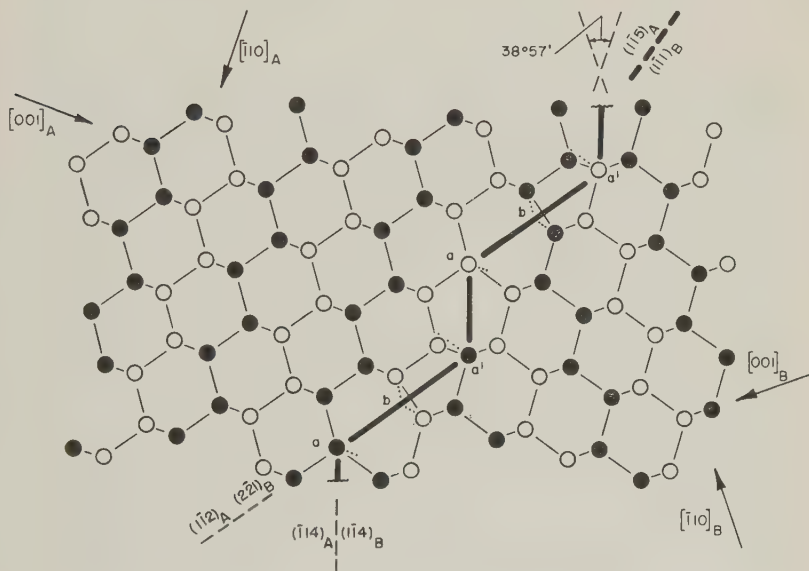


FIG. 10. $\{115\}$ - $\{111\}$ second-order twin join.

tions having seven, five, and six (altered) sides. The change in bonding at position b is the same as in the previous construction. The changes at a and a' are the same as at the similarly designated positions in the four first-order boundaries. The atoms at a require three nearest neighbors; those at a' require five. The two abnormally coordinated sites are separated by only 1.9 times the usual bond distance, permitting an adjustment of the structure to alleviate the condition. The deviations from undistorted bonding along the $\{115\}$ - $\{111\}$ second-order twin join are the same, in both type and sequence, as those noted for the $\{115\}$ - $\{111\}$ first-order boundary (Fig. 4). In fact, the only difference between these two discontinuities lies in the shapes of the arrays formed by projected trans-boundary atomic configuration. The $\{115\}$ - $\{111\}$ second-order twin join is the only boundary discussed herein which was not observed in the silicon specimen studied.

The last zig-zag discontinuity for second-order twinning has a resultant

direction along $(\bar{1}14)$ of individual A and $(\bar{1}\bar{1}4)$ of individual B; it is shown in Fig. 11. The boundary oscillates among segments having directions along $(\bar{1}\bar{1}2)_A$ - $(221)_B$, $(\bar{1}14)_A$ - $(114)_B$, and $(221)_A$ - $(\bar{1}\bar{1}2)_B$. The trans-boundary atomic configuration projected along two adjacent boundary segments shows arrays having seven, five, and six (altered) sides. The bonding changes at a , a' , and b are the same as in the previous construc-

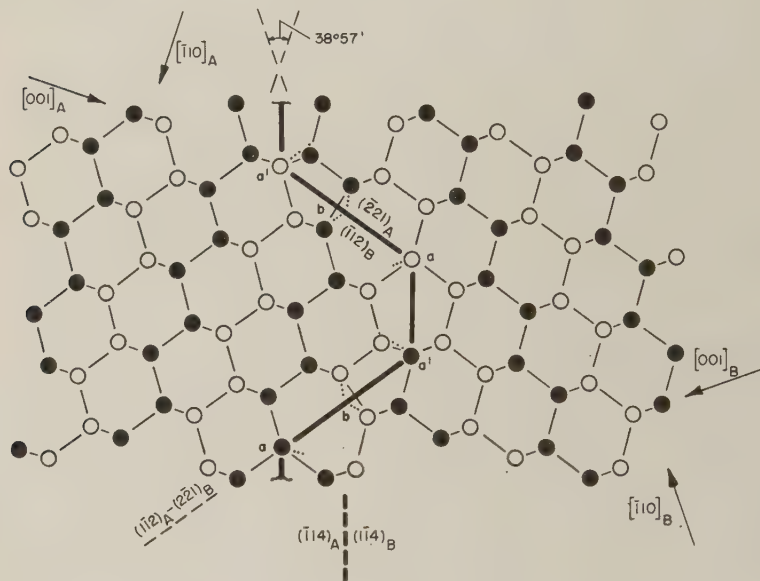


FIG. 11. $\{114\}$ - $\{114\}$ second-order twin join.

tion (Fig. 10); the boundary differs from that shown in Fig. 10 only in the direction reversals of the former. The trans-boundary structure of the $\{114\}$ - $\{114\}$ second-order zig-zag discontinuity is also very similar to that of the $\{112\}$ - $\{112\}$ first-order boundary (Fig. 5). See Table 1 and Fig. 1 for comparison with experimental results.

THIRD-ORDER TWINNING

The (110) -projected coincidence site superlattice for third-order twinning has approximately one-third the site density of the net derived by second-order twinning (Fig. 8). It consists of regions $1.3a_0$ wide, susceptible to structural restoration; these are separated by non-restorable areas $3.9a_0$ in width. No possibility exists for an $(h\bar{h}l)$ third-order twin join restorable along its entire length; partial restoration, however, is possible.

The boundaries designated III₁ in Fig. 1 and referred to in *Experimen-*

tal Results are apparently of the second-order type, i.e., they seemingly represent discontinuities between individual A (light gray) and B (black). When the observed boundary direction, however, was plotted on the coincidence site superlattice for second-order twinning, no restorable zig-zag discontinuity could be constructed. Further examination of these areas was made in an attempt to account for the apparently anomalous behavior. High magnification revealed that an additional twinning was involved. Figure 12 is an enlargement of one of these areas (circled in Fig.

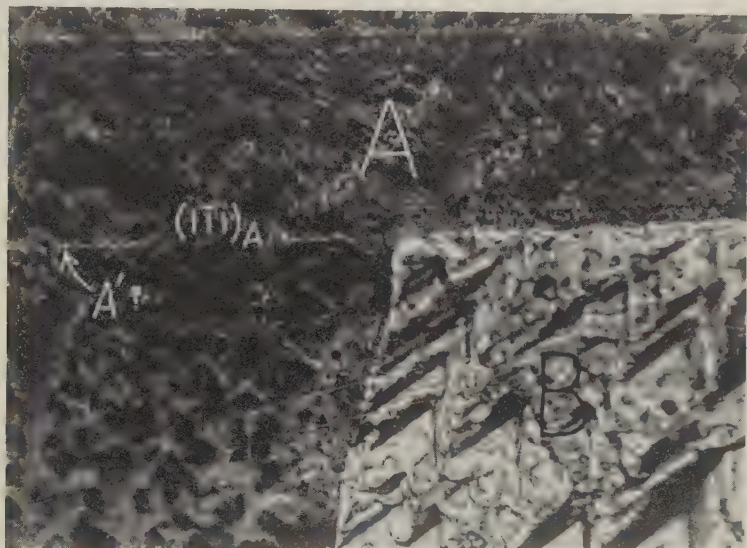


FIG. 12. Enlargement of circled area in Fig. 1, showing the additional twin lamella at the point of the "step." 470X.

1); the additional twin lamella can clearly be seen in individual A emanating from the point of the "step." Thus, the seemingly anomalous boundaries are not second-order twin joins. It was not clear, however, whether the thin lamella represented, on the part of individual A, a twinning back to the host orientation, or whether a new orientation, A' , had been generated. In the latter case, the boundary in question would be a third-order twin join, whereas if the former were true, it would be a first-order lateral twin boundary. X-ray diffraction was to no avail in deciding this point, since the lamella was too thin.

If individual A has twinned back to host orientation, it has done so by means of a $(115)_H-(111)_A$ lateral twin boundary. The resultant discontinuity between the host lamella and individual B is very close to a $(114)_H-(110)_B$ lateral twin boundary; the misfit is $3^\circ 41'$. Examination of

the areas in question at magnifications up to $1000\times$ failed to reveal any evidence for a boundary rotation of this amount. On the other hand, if the lamella represents a new orientation, A' , generated from A , the twin boundary ($A:A'$) involved is of the usual first-order type, i.e., $(\bar{1}\bar{1}1)_A - (\bar{1}\bar{1}1)_{A'}$ (Fig. 12). The resultant contact surface between individuals A' and B , as stated above, is a third-order twin join, specifically $(\bar{1}\bar{1}1)_{A'} - (11\bar{1}1)_B$. The latter discontinuity follows a row of sites in the third-order coincidence site superlattice. The boundary is restorable, in the sense used herein, along approximately 25% of its length. The latter explanation for these seemingly anomalous areas appears to be more plausible. From an animistic point of view, the silicon crystal, faced with the possibility of developing a non-restorable second-order twin join, twins again in order that the discontinuity (now third-order) achieve at least a certain degree of restoration; the lower energy state is selected. In this connection, Haasen (15) has noted in indium antimonide that twins of the same matrix sometimes twin again to "avoid direct contact with one another."

Fourth-order twinning in the diamond structure results in no lattice sites common to both individuals. Accordingly, trans-boundary restoration is lacking, and the discontinuity probably approaches that of a common (non-twin-related) grain boundary, i.e., a high-energy discontinuity.

GRAIN BOUNDARY ENERGY

Read and Shockley (10), in their theoretical treatment of a boundary between two crystals which have a crystallographic direction in common and a small angular misfit, derived the relation

$$E = \frac{Ga(\cos\phi + \sin\phi)}{4\pi(1-\sigma)} \theta(A - \ln\theta)$$

for an isotropic cubic metal. E is the energy per unit area of the grain boundary, G represents the rigidity modulus, a is the lattice constant, ϕ is the inclination of the boundary from the symmetry position, σ is Poisson's ratio, θ represents the orientation difference between the lattices, and A is an arbitrary constant. In plotting E vs. θ , the theory calls for a rapid increase in energy with θ , followed by a less pronounced decrease. Excellent agreement is obtained with experimental determinations of relative grain boundary energy as a function of orientation, as carried out, for example, on silicon-iron (19), tin (20), lead (21), and silver (22). These data are summarized by Smith (23).

In the case of grain boundaries derived by twinning, the relative rotation angle, θ , is established, being $70^\circ 32'$ for first-order twinning, $38^\circ 57'$

for second-order, and $31^{\circ}35'$ for third-order. The various lateral twin boundaries and high-order twin joins offer different values of ϕ (grain boundary orientation) for constant values of θ . Read and Shockley (10) have shown that the E vs. θ curve contains low-energy cusps when the two crystals are in register on the same atom at regular intervals; the θ values corresponding to twinning orientations represent low-energy cusps. These authors have further reasoned that similar effects will be produced by varying ϕ , that is, large differences in energy are produced for a given θ by changes in orientation of the grain boundary. (They predicted energy cusps in first-order twin-related grains for $\{111\}-\{111\}$, $\{110\}-\{114\}$, and $\{112\}-\{112\}$; a cusp for the [second-order] twin join $\{221\}-\{221\}$ was also mentioned.) This conclusion has been borne out by experimentation. Lacombe (24), for example, noted that in aluminum the rate of boundary etching was strongly dependent upon the orientation of the boundary between twin grains, the attack on a $\{111\}-\{111\}$ twin boundary being relatively negligible; Shuttleworth, King, and Chalmers (25) had similar results with silver. Dunn, Daniels and Bolton (18) found an energy cusp for the $\{112\}-\{112\}$ twin boundary in silicon-iron and for a $\{110\}-\{110\}$ second-order twin join; they measured the energy of the $\{112\}-\{112\}$ boundary as 22 per cent of that of "ordinary boundaries." In copper, Fullman (26) measured the ratio of the interfacial free energy of coherent twin boundaries [$\{111\}-\{111\}$] to the "average grain boundary" free energy as 0.035. Fullman (27) also studied "noncoherent" twin boundaries in copper and found by measurement that a boundary "approximately parallel to a $\{113\}$ plane of one crystal and a $\{335\}$ plane of the other" had an interfacial free energy equal to 80 per cent of that of the "average grain boundary" free energy. In another paper, Fullman (28) measured the ratio of twin boundary energy [$\{111\}-\{111\}$] to "average grain boundary" energy in aluminum as 0.21.

The foregoing experimental data serve to establish that boundary orientation can have a decided effect on grain boundary energy. Further, higher energies are involved as one progresses through the boundary sequence wherein (a) twin plane and composition plane are coincident, (b) twin plane and composition plane are not coincident (lateral twin boundaries and high-order twin joins), and finally (c) the grains are unrelated by twinning. The boundaries proposed in the present study for diamond-type materials are of class (b). The four ($h\bar{h}l$) lateral twin boundaries represent low energy cusps for $\theta=70^{\circ}32'$. Two are newly-proposed, $\{115\}-\{111\}$ and $\{001\}-\{221\}$; all have been experimentally observed (Fig. 1 and Table 1). The three ($h\bar{h}l$) second-order twin joins correspond with low energy cusps for $\theta=38^{\circ}57'$. One is newly-proposed, $\{115\}-$

TABLE 2. DEVIATIONS FROM UNDISTORTED BONDING (ALONG BOUNDARY LENGTH OF $4.1 a_0$)

	$3\ddagger$ Nearest neighbors (symbol a)	$5\ddagger$ Nearest neighbors (symbol a')	$a:a'$ Spacing	2 bonds to 1 at $19^\circ 28'$ 6% shortening (symbol b)	Undistorted 4 nearest neighbors (symbol c)	Distorted 4 nearest neighbors (symbol d)
$\{110\}-\{114\}^*$	1	1	3.4§	1	3	0
$\{221\}-\{221\}^\dagger$	0	0	—	3	0	3.5
$\{115\}-\{111\}^*$	2	2	1.9	2	0	0
$\{112\}-\{112\}^*$	2	2	1.9	2	0	0
$\{115\}-\{111\}^\dagger$	2	2	1.9	2	0	0
$\{114\}-\{114\}^\dagger$	2	2	1.9	2	0	0
$\{001\}-\{221\}^*$	1.75	1.75	3.4	1.5	1.5	0

* First-order.

† Second-order.

‡ The structure, of course, will adjust to alleviate these abnormal coordinations.

§ Times normal bond length.

Four of the listed boundaries show the same deviations from undistorted bonding and would accordingly have similar energies.

$\{111\}$; all but the latter have been experimentally observed (Fig. 1 and Table 1).

As stated previously herein, the energy of a particular grain boundary increases with the specific deviations from undistorted bonding. Such deviations are listed in Table 2 for the seven zig-zag discontinuities described in the present study.

SUMMARY

By an analysis of (110)-projected coincidence site superlattices in the diamond structure, seven permissible, "low-energy," ($h\bar{h}l$) boundaries are derived and constructed; four refer to first-order twin-related grains and three to a second-order twin relationship. Two of the former and one of the latter are newly-proposed. The boundary directions follow rows of sites in the respective coincidence site superlattice. A considerable degree of trans-boundary structural restoration can be achieved if an oscillating, or zig-zag mechanism is used for the discontinuity surface. The seven ($h\bar{h}l$) boundaries described for the diamond structure, and only these, are amenable to such restoration in addition to having high coincidence site density. Six of the discontinuities have been observed in the same silicon specimen, in addition to the normal $\{111\}-\{111\}$ boundary; no others were found for first- or second-order twinning.

Instances of probable third-order twinning have been noted in silicon.

The additional twin lamellae at these positions reflect the tendency of the crystal to avoid a non-restorable second-order twin join in favor of a partially-restorable third-order boundary.

Boundary orientation can have a pronounced effect on grain boundary energy. The seven structurally-restorable discontinuities described herein represent low-energy cusps in the curve relating energy and boundary direction, for constant misfit angles. Experimentation has previously shown that such boundaries are intermediate in energy between those in which twin plane and composition plane are coincident (usual case) and those involving a common, non-twin-related grain boundary.

Lateral twin boundaries and high-order twin joins in semiconductor materials are expected to affect structure-sensitive electrical properties, e.g., minority carrier lifetime and carrier mobility. Additionally, such boundaries, owing to their association with low-energy cusps, have a practical bearing upon semiconductor devices whose functioning depends upon high-energy grain boundaries.

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REFERENCES

1. MATARÉ, H. F., AND REED, B., *Z. Naturforschg.* **11a**, 876-8 (1956).
2. SLAWSON, C. B. *Am. Mineral.* **35**, 193-206 (1950).
3. KOHN, J. A., *Ind. Diamond Rev.* **13**, 56-7 (1953).
4. KOHN, J. A., *Am. Mineral.* **41**, 778-84 (1956).
5. MATARÉ, H. F., Sylvania Electric Products, Inc., Bayside, L.I., N.Y., personal communication.
6. KAISER, W., AND KOHN, J. A., *Acta Met.* **4**, 220-1 (1956).
7. ELLIS, W. C., AND TREUTING, R. G., *Jour. Metals* **3**, 53-5 (1951).
8. MATARÉ, H. F., *Z. Physik* **145**, 206-34 (1956).
9. READ, W. T., JR., *Dislocations in Crystals*, McGraw-Hill, New York, 159 (1953).
10. READ, W. T., JR. AND SHOCKLEY, W., *Phys. Rev.* **78**, 275-89 (1950).
11. TEAL, G. K., AND LITTLE, J. B., *Phys. Rev.* **78**, 647 (1950).
12. KECK, P. H., VAN HORN, W., AND MACDONALD, A., *Rev. Sci. Instr.* **25**, 331-4 (1954).
13. BILLIG, E., *Jour. Inst. Metals* **83**, 53-6 (1954).
14. GRENINGER, A. B., *Trans. AIME* **122**, 74-120 (1936).
15. HAASEN, P., *Jour. Metals* **9**, 30-2 (1957).
16. CHURCHMAN, A. T., GEACH, G. A., AND WINTON, J., *Proc. Roy. Soc.* **238A**, 194-203 (1956).

17. SALKOVITZ, E. I., AND VON BATCHELDER, F. W., *Jour. Metals* **4**, 165 (1952).
18. DUNN, C. G., DANIELS, F. W., AND BOLTON, M. J., *Jour. Metals* **2**, 368-77 (1950).
19. DUNN, C. G., AND LIONETTI, F., *Jour. Metals* **1**, 125-32 (1949).
20. AUST, K. T., AND CHALMERS, B., *Proc. Roy. Soc.* **201A**, 210-15 (1950).
21. AUST, K. T., AND CHALMERS, B., *Proc. Roy. Soc.* **204A**, 359-66 (1950).
22. GREENOUGH, A. P., AND KING, R., *Jour. Inst. Metals* **79**, 415-27 (1951).
23. SMITH, C. S., *Inst. intern. phys. Solvay, 9th. Conseil, Brussels, État solide*, 11-53 (1951)
24. LACOMBE, P., Bristol Conf. on Strength of Solids (1947), published by Phys. Soc London (1948).
25. SHUTTLEWORTH, R., KING, R., AND CHALMERS, B., *Nature* **158**, 482-3 (1946).
26. FULLMAN, R. L., *Jour. Appl. Phys.* **22**, 448-55 (1951).
27. FULLMAN, R. L., *Jour. Appl. Phys.*, **22**, 456-60 (1951).
28. FULLMAN, R. L., *Gen. Elec. Co. Res. Rept.* No. **RL422**, Sept. 1950 (cf. p. 21 of reference 23).

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PRODUCTION OF GRAPHITE SINGLE CRYSTALS BY THE THERMAL DECOMPOSITION OF ALUMINUM CARBIDE

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ABSTRACT

Aluminum carbide, Al_4C_3 , dissociates in the vicinity of 2200–2500° C., at atmospheric pressure, to aluminum vapor and graphitic carbon. Under suitable geometry and heating conditions large, pure, single crystals of graphite can be produced. The crystals have an unusual morphology. In no case is the macroscopic hexagonal symmetry evident. All crystals show growth lines and steps that presumably carry over from the carbide precursor. Twinning and cleavage are common but less frequent than in graphite from other sources. An interlayer spacing of $3.3545 \pm 0.0005 \text{ \AA}$ at 25° C. was measured.

INTRODUCTION

Graphite exhibits a number of interesting properties that are associated with the high degree of anisotropy in directions parallel and perpendicular to the *c*-axis. This anisotropy is associated with a unique distribution of electrons, which are more-or-less free to move through the carbon net parallel to the basal plane, but are constrained from movement from one net to another. The graphite lattice has strongly bonded carbons at essentially the closest possible distance of approach (1.42 Å) in the carbon net, but adjacent nets are bonded by only coulombic attraction, and are about 3.35 Å apart.

The anisotropy of graphite can best be investigated on single crystals. The inaccessible melting point and the extremely low sublimation pressure preclude the preparation of large crystals by conventional techniques.

Most carbonaceous material graphitizes at temperatures above 1500° C., more completely the higher the temperature. The crystallite size is very small, however, and the interlayer spacing of the classical graphite lattice is approached only at the highest accessible temperature.

Fairly large (a few millimeters) graphite crystals can be grown from an iron melt saturated with carbon. Cooling the surface of such a melt by a stream of gas (1), or rapidly cooling the liquid by plunging a cold object into it, causes precipitation of single crystals that float to the surface. Graphite produced in this way is invariably contaminated with iron. Crystals prepared by the authors contained approximately 10% iron by weight, and were magnetic. Undoubtedly, most of the iron is mechanical contamination and its removal by acid treatment should not affect the structure of the graphite crystals. It is questionable, however, whether all of the iron is mechanically occluded, and whether iron removal treat-

ments, such as high temperature chlorination, could remove it completely without affecting the crystal.

By far, the greater number of measurements on crystalline graphite have employed flakes of natural graphite, cleaved from pieces that had been separated from the matrix of limestone and other material where they occur.

Dutta (2) reported electrical measurements on natural, single crystals of Ceylon graphite that were one to two centimeters on a side, and about a half millimeter thick. They were cut from a larger crystal that was stated to be free of impurities, and showed no twinning or strains. It would be remarkable if a crystal of that size and perfection could be found in the natural state free of the profusion of impurities that ordinarily accompany natural graphite. Possibly, the examination of the specimens was only of a cursory nature. More frequently, natural graphite that can be considered as single crystals by most criteria is in the form of tiny flakes, two or three millimeters in the largest dimension, such as described by Palache (3), and Primak and Fuchs (4).

It would be expected that the carbides of all but the most refractory metals should yield graphite at temperatures where the compounds dissociate and the metal is volatilized. To the writers' knowledge, the various possibilities have not been explored.

Aluminum carbide, Al_4C_3 , is an attractive starting material because it can be grown in large single crystals, and considerable is known about its chemical stability. Thermal data on aluminum carbide are sparse. Gross* determined the heat of formation at 900°C . as -32 kcal./mole . From known heat capacities of aluminum and carbon, and an approximation for that of aluminum carbide, it is calculated that the free energy of formation at 2000°C . is -24 kcal./mole. , corresponding to an aluminum dissociation pressure of about 30 mm. This must be considered very approximate. At the same temperature, the sublimation pressure of carbon is negligible.

This paper describes the preparation of large, pure, single crystals of graphite by the thermal decomposition of pure aluminum carbide at temperatures in excess of 2000°C .

EXPERIMENTAL

Preparation of Aluminum Carbide

At moderate temperatures, aluminum should react to completion in the presence of excess carbon to form aluminum carbide. When the amount of exposed carbon surface is limited, however, the layer of carbide that forms at the carbon-aluminum interface inhibits further reac-

* Gross, P., Private communication.

tion, and the solution appears to be stable. Figure 1 shows a section through aluminum that had been held at about 1800°C . in a graphite crucible. The precipitated yellow carbide plates that appear separated in the illustration actually communicate in the three-dimensional piece, and the mass exhibits a brittle fracture, although it consists predominantly of ductile aluminum.

Under no conditions will free carbon precipitate from an aluminum-

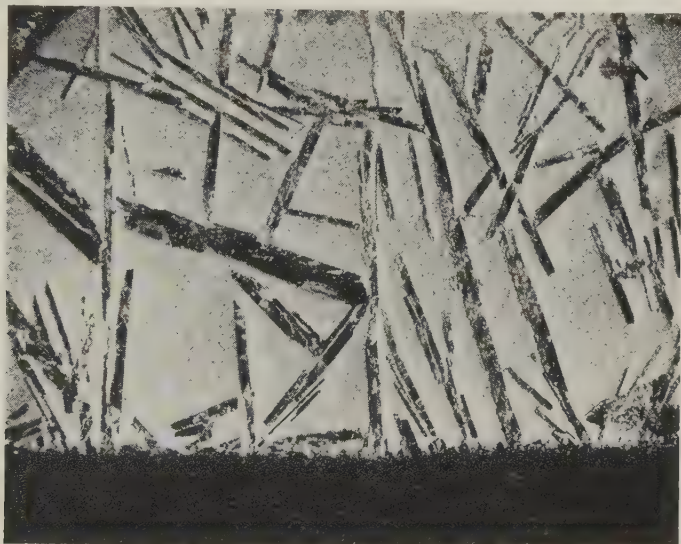


FIG. 1. Polished section of aluminum that had been held at 1800°C . in a graphite crucible. The plates that appear black are yellow transparent aluminum carbide. Mag. $19\times$.

aluminum carbide solution. If a mixture, such as that shown in Fig. 1, is heated in vacuum, the excess aluminum vaporizes readily at about 1800°C ., to leave a residue of large, single crystals of aluminum carbide.

This method of preparation is troublesome, because large quantities of aluminum condense in the lining and insulation of the furnace. A more satisfactory synthesis consists of heating lampblack and atomized aluminum powder in the stoichiometric ratio to make aluminum carbide. Complete reaction is obtained when the ball-milled mixture is held at 1850°C . in an argon atmosphere for approximately two hours. The product is yellow-orange and, though partially sintered, it can be crumbled readily by hand. The crystal size varies, depending on the heating conditions, but 0.1 to 1 mm. is a typical range.

The product is shown to be pure, stoichiometric aluminum carbide by x-ray examination, and by methane evolution in hydrochloric acid,

Preparation of Graphite Crystals

Aluminum carbide converts readily to graphite on heating above 2000° C. in vacuum, or to somewhat higher temperatures in inert atmospheres. However, in order to grow large crystals, it is necessary that the geometry of the charge and the heating conditions be such as to grow large carbide crystals first. Although large carbide crystals are necessary precursors, they do not assure large graphite crystals. In one experiment where large, perfect carbide crystals, contained loosely in an open graphite crucible, were heated in high vacuum to 2500° C., the graphite product was microcrystalline. The best product was obtained when the optimum geometry for growth of the carbide crystals was maintained during further heating to the dissociation temperature.

The following procedure gave the best graphite crystals. Aluminum carbide was ground to -325 mesh. A rough cylinder, approximately 4 cm. in diameter by 8 cm. long, was hydrostatically pressed at about 60,000 psi in a high pressure, oil-filled bomb. The fine particle size was necessary to give adequate green strength to the pressed body. A 1-cm. hole was drilled axially through the cylinder. The cylinder was placed in a loose-fitting, graphite tube in a horizontal induction-heated furnace that was equipped with graphite radiation shields at either end. The charge was heated slowly so that it reached about 2400° C. in 4 hours. It was held at that temperature for an additional 2 hours, then slowly cooled by reducing the power to the induction coil. Purified argon was passed through the unit at atmospheric pressure at approximately 40 ml./minute throughout the entire heating cycle.

The temperature was measured at the hottest part of the charge that could be seen through axial holes in the radiation shields. Undoubtedly, part of the charge that was hidden from view was at a higher temperature. However, previous experience with the furnace had indicated that temperature differentials exceeding 100° C. were unlikely.

On occasions, part of the charge appeared to melt. Since aluminum carbide probably does not melt, per se, it is assumed that in those cases aluminum vaporized from the hottest part of the charge, condensed onto the cooler parts, and dissolved the carbide to produce the liquid phase.

The largest graphite crystals were found growing into the axial hole in the charge and into voids throughout the charge that had resulted from shrinkage or cracking during the heating period. Those are the places where the largest carbide crystals would have been found had the heating been interrupted before the dissociation temperature was reached.

Figure 2 shows transparent, yellow aluminum carbide plates before

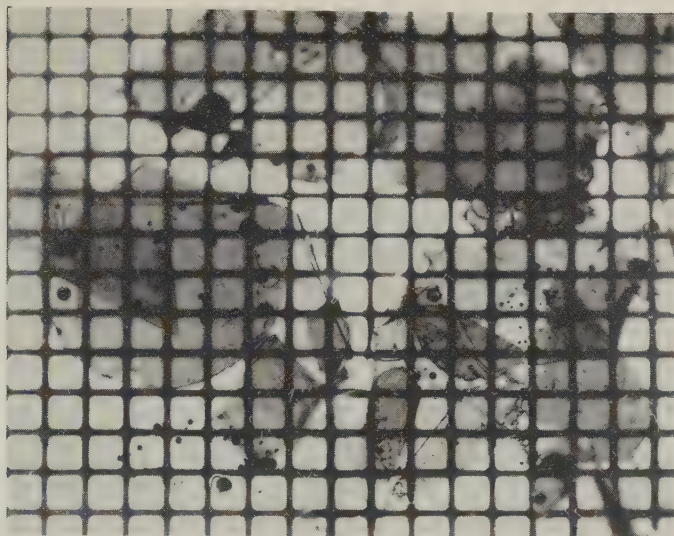


FIG. 2. Single crystals of aluminum carbide supported on a fine mesh screen to show their transparency. The small black dots are droplets of metallic aluminum that condensed on the crystals during cooling. Mag. 14X.

their conversion to graphite. Figure 3 shows a charge and the containing graphite tube broken open after completion of the graphitization. The largest graphite crystals are seen in the center.

PROPERTIES OF GRAPHITE CRYSTALS

Purity

The most likely impurities in the graphite would be free aluminum and unreacted aluminum carbide. Because of the temperature gradients, the charge was seldom completely converted to graphite throughout. Moreover, aluminum carbide was everywhere in the furnace, either blown about mechanically by the argon stream, or formed by reaction of the vaporized aluminum with the carbon furnace parts. There was never complete assurance, therefore, that a large enough sample of graphite for analysis could be recovered without the possibility of mechanical inclusion of aluminum or aluminum carbide.

Purity was established on a sample of approximately 0.075 g. of the cleanest appearing crystals that had been leached free of occluded aluminum carbide with dilute hydrochloric acid. The crystals were not visibly altered during this treatment, and it is likely that the acid removed only the admixed carbide and aluminum that had been visible as tiny particles under the microscope.

The crystals exhibited amazing retention of the acid. Repeated washing over a three-week period did not completely remove the hydrogen ion. This treatment would not be expected to produce lamellar or residual compounds, so perhaps the acid was only mechanically entrapped.

Ignition of the sample at 800°C . left no residual ash within the weighing precision of an ordinary analytical balance. Furthermore, micro-

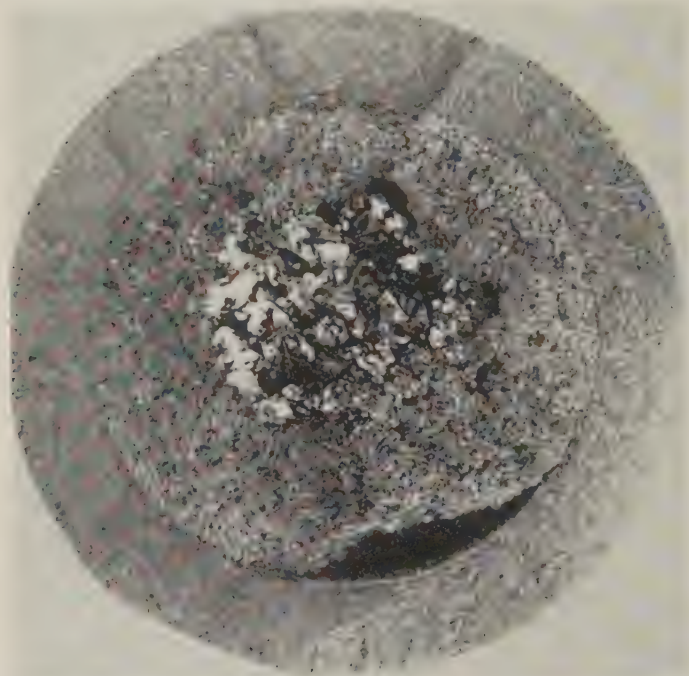


FIG. 3. Graphite crystals formed in the center of a charge of aluminum carbide that had been held at 2400°C . Mag. $2\times$.

scopic examination of the platinum ashing crucible showed no residue that could be attributed to the graphite.

X-RAY PROPERTIES

The interlayer spacing was measured on a Norelco diffractometer. The spacing was obtained by extrapolating to zero ($\theta = 90^{\circ}$) the plot of d -values, calculated from the 002, 004, 006, and 008 reflections, versus $\cos \theta \cos^2 \theta$. The crystals were oriented with the basal planes parallel to accentuate those reflections. An interlayer spacing of $3.3545 \pm 0.0005 \text{ \AA}$ at 25°C . was determined on one lot of particularly fine crystals.

A number of Laue patterns were made of carefully selected crystals,

In only one instance was a pattern obtained that showed simple sixfold symmetry of a single individual. More frequently, the spots indicated two or more individuals with common *c*-axes, rotated slightly with respect to one another. The persistent rotation between two individuals of $2\frac{1}{2}^\circ$, that was reported by Lukesh (5), generally was not observed.

Powder patterns of finely ground crystals showed extra lines corresponding to a few per cent of the rhombohedral modification, which was first reported by Lipson and Stokes (6). Although the source of these extra lines was controversial a few years ago, it now appears that the phenomenon can be adequately described by the alternative stacking sequence of ABCABC, in the rhombohedral modification, rather than the ABABAB stacking for the usual hexagonal form. This situation has been well described by Laves and Baskin (7), and others, and will not be discussed here. It was not established whether the rhombohedral modification existed in the single crystals or was produced by grinding for the powder patterns.

TWINNING

Twinning, of the type described by Palache (3), and Laves and Baskin (7), could easily be observed, although growth twins were infrequent. Perhaps only one out of ten crystals from a good lot showed twins that could be detected by light reflection under a microscope, if they were carefully handled so as not to induce mechanical twinning. Mechanical twinning could be induced very easily by pressing a sharp point into the flat surface of a crystal. Such a twin could be led over the crystal in a striking manner by drawing the point along the surface.

MORPHOLOGY

The most striking characteristic of the graphite crystals is the unusual crystal form. This is best illustrated by Figs. 4-7. In contrast to crystals grown from iron (Fig. 8), which clearly show the hexagonal symmetry, crystals from the decomposition of aluminum carbide in no instance showed a straight edge or a well-defined angle. On the other hand, growth lines and steps that are indistinct or absent in graphite from other sources were most pronounced in all of the specimens of carbide graphite that were examined. Similar growth lines can be seen in most aluminum carbide crystals and it is assumed that these carry over in some fashion to the graphite. In addition to growth lines, however, most carbide crystals show one or more hexagonal angles. Figures 4A and B show typical graphite crystals. No twinning is apparent. The spallation in the center of the crystal of Fig. 4A is a typical defect resulting from cleavage of a thin layer off the surface of the crystal. This might have been caused by



FIG. 4. Typical crystals of graphite produced by thermal decomposition of aluminum carbide. Mag. 25 \times .

handling the crystal after it was prepared. Figure 5 shows twinned crystals. Figure 5A shows profuse twinning. This was rare in the samples under study, although it is characteristic of natural graphite crystals. Figure 5B shows a crystal that was untwinned initially, but was mechanically twinned by pressing the point of a pencil into the surface at the position where the twin lines originate. Figure 6 is the largest crystal showing no twinning or cleavage that was found in a cursory examination of several hundred specimens. This crystal is approximately $\frac{1}{4}$ inch long.

Figure 7 shows a crystal with two pronounced twin lines, one showing as a dark, black shadow and the other as a light band. These twins are seen to go through the growth rings uninterrupted and without change of direction.

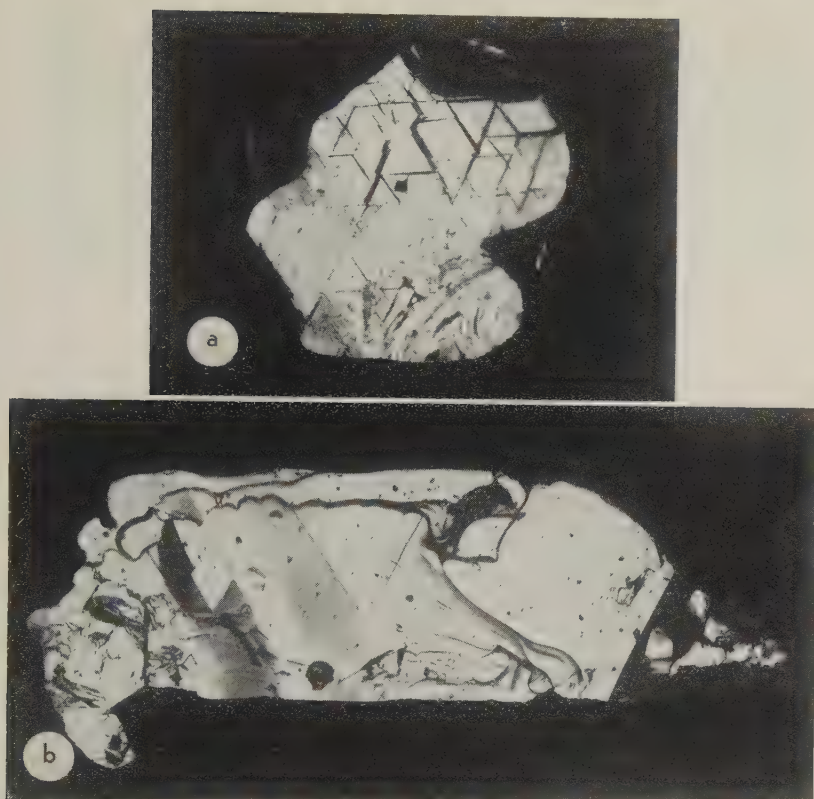


FIG. 5. (a) Graphite crystal showing extensive twinning. (b) Graphite crystal showing mechanical twinning. Mag. 25X.

DISCUSSION

It is possible that aluminum carbide is unique among the metal carbides in its ability to form large single graphite crystals by volatilization of the metal cation. The temperature where the conversion to graphite occurs is much lower than the temperature where amorphous or microcrystalline carbon would be expected to become ordered to give the near-classical *c*-spacing. It appears then, that the conversion must entail a systematic diffusion of aluminum atoms and contraction of the carbon lattice.

The Group III metals are the least electropositive elements that form salt-like carbides, where the lattice is determined by packing of the carbon atoms. The Group IV, V, and VI metals are too large to fit in the interstices between carbons, and the structure is determined by the metal atom packing. These latter carbides are usually referred to as interstitial carbides.

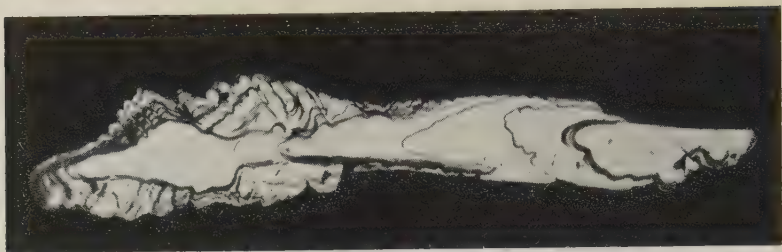


FIG. 6. Large graphite crystal free of cleavage and twinning. Mag. 15 \times .

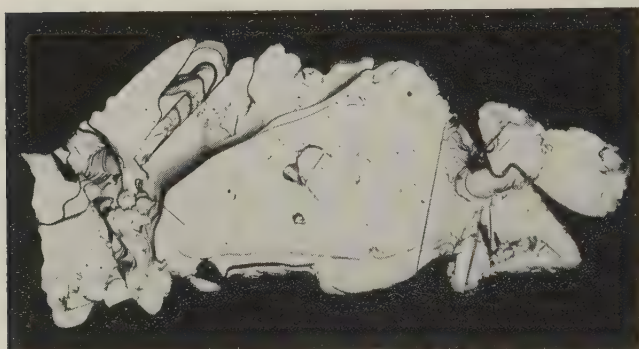


FIG. 7. Graphite crystal showing two parallel twin lines that extend through growth lines. Mag. 12 \times .

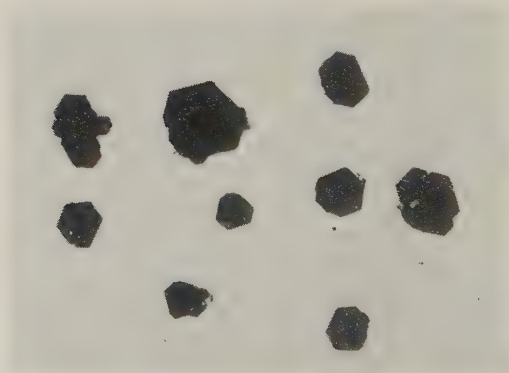


FIG. 8. Graphite crystallites grown from an iron-carbon melt. Mag. 25 \times .

Of the metals that form salt-like carbides, only beryllium and aluminum are sufficiently small to be contained in the equivalent tetrahedral cavities between the carbons in the number required to satisfy their normal chemical valence. This results in hexagonal, lamellar crystals that exhibit cleavage through the planes that separate stoichiometric units. This lamellar character might well be a requirement for any crystal to dissociate to a lamellar product.

Beryllium carbide emerges as the only crystal, besides aluminum carbide, that would be expected to dissociate to the free metal and macrocrystalline graphite. However, the lower vapor pressure of beryllium would necessitate a higher dissociation temperature to effect the complete removal of beryllium from the product.

The structure of aluminum carbide was determined by Stackelberg and Schnorrenberg (8). The crystal is hexagonal with a layer lattice. Each layer consists of four aluminum and three carbon atom planes. The four aluminum planes lie over one another in what would be cubic close packing, except for the interposed carbon planes. The cubic packing is disrupted at the boundary of a layer in such a way that two outer aluminum planes in one layer and the first aluminum plane in an adjacent layer are hexagonally close packed. Between the aluminum planes lie three carbon planes, one of which forms the middle plane of the layer. This C_I plane is flanked on each side by an Al_I plane. These are followed by C_{II} planes, and finally on each side by an Al_{II} plane, which terminates the layer. The next layer begins with an Al_{II} plane. Each layer thus has the stoichiometric Al_4C_3 composition with saturated valences, and the boundary of the layer constitutes the cleavage plane along the horizontal base. The arrangement of the carbon planes is somewhat similar to that of the aluminum planes. That is, the packing is hexagonal across the layer boundary and cubic within the layer.

It is interesting to speculate how these carbon layers can transform to the graphite structure. In the carbon planes of aluminum carbide there are approximately 0.105 carbons/ \AA^2 , compared to 0.382 carbons/ \AA^2 in the graphite carbon net. This suggests a condensation of the three carbon planes of a carbide layer to form one carbon net of approximately three times the carbon density. Two adjacent planes, merging along the c -axis, produce an open-center, carbon net. The C—C distance is 1.92 \AA , ($\frac{1}{3}\sqrt{3}a$), however, and appreciable contraction would be required to reach the 1.42 \AA spacing in the graphite net. If the third carbon plane compresses along the c -axis, without rotation, the atoms go into the center of the open net formed by the previous two, to give full hexagonal symmetry with one atom in the center of a hexagon whose side is still 1.92 \AA . There is no obvious way that this layer could transform to the

open carbon net of graphite with a C—C distance of 1.42 Å, without appreciable atom shift and the loss, momentarily, of the hexagonal symmetry. The complete absence of straight sides and well-defined angles in the graphite crystals suggest that considerable atom shift or rotation of carbon planes does take place during the transformation. It is reasonable that, at the high temperature the loss of aluminum by diffusion, and the compression and reorientation of carbon planes, takes place simultaneously in a reaction zone or front that progresses across the crystal with the thermal gradient.

The smallest *c*-spacing found experimentally on graphite crystals is not well identified in published reports. The value of 6.696 Å appears frequently. Lukesh (6), however, cites the same value in *kx* units (6.696 *kx* units = 6.709 Å). The best value that was found in a cursory examination of the literature was the interlayer spacing of 3.3538 ± 0.0005 Å, at room temperature, for a single crystal of natural graphite, that was determined by Baskin and Meyer by an extrapolation method (9). The same authors found 3.3542 Å for natural graphite powder, and 3.3600 Å for artificial graphite powder.

It appears that the interlayer spacing in the graphite crystals produced from aluminum carbide is acceptably low, and might well be comparable to the lowest spacing ever reported. It would be interesting to see if a higher dissociation temperature would result in an even smaller spacing.

The low *c*-spacing, combined with chemical purity, large size, and general absence of cleavage and twinning, make these crystals attractive for more precise investigation of the properties of graphite. The authors feel that with larger furnace equipment, capable of going to higher temperatures, crystals at least $\frac{1}{2}$ inch across could be prepared.

ACKNOWLEDGMENT

The authors are indebted to Mr. William Graff for the photographs of the graphite crystals.

REFERENCES

1. NIWA, K., AND SHIMAOKA, G. J. *of Metals*, **9**, 430–4, 1957.
2. DUTTA, A. K. *Phys. Rev.*, **90**, 187–92, 1953.
3. PALACHE, C. *Am. Mineral.*, **26**, 709–17, 1941.
4. PRIMAK, W., AND FUCHS, L. H. *Phys. Rev.*, **95**, 22–30, 1954.
5. LUKESH, J. S. *J. Chem., Phys.*, **19**, 383–4, 1951.
6. LIPSON, H., AND STOKES, A. R. *Proc. Roy. Soc.*, **A181**, 101–5, 1942.
7. LAVES, F., AND BASKIN, Y. *Zeit. Krist.*, **107**, 337–56, 1956.
8. STACKELBERG, M. V., AND SCHNORRENBERG, E. *Z. Physik. Chem.*, **27**, 37–49, 1934.
9. BASKIN, Y., AND MEYER L., *Phys. Rev.* **100**, 544, 1955.

Manuscript received July 21, 1957

MEMORIAL OF GEORGE DAVIS LOUDERBACK

A. PABST, *University of California, Berkeley.*

George Davis Louderback, a charter fellow of the Mineralogical Society of America, was born in San Francisco, on April 6, 1874, and died in Berkeley, California, on January 27, 1957. He entered the University of California in 1892 and in 1896 received the A.B. degree. In 1899 he was awarded the Ph.D. degree by the University of California, his thesis being entitled "On the Origin of the Glauconite and Associated Schists of the Coast Ranges. A Contribution to the Theory of the Crystalline Schists." This thesis was never published and has been listed by the University as "not available," though it is clear that Dr. Louderback's interest in these studies continued for several years as indicated by part of a one page note entitled "Study of the Basin Range structure and glauconite and related schists of California and Oregon," *Carnegie Inst. Wash. Yearbook* 4: 161 (1906) and an abstract of 7 lines entitled "Crocoidolite-bearing rocks of the California coast ranges," *Bull. Geol. Soc. Am.* 18: 659 (1908).

From 1900 to 1906 Dr. Louderback was professor of geology and mineralogy in the University of Nevada. He then returned to Berkeley and served as a member of the Geology Department from 1906 to his retirement in 1944. He also held numerous posts in various scientific, academic and governmental bodies. Only a few will be mentioned at this point. Professor Louderback was a charter member of the Cordilleran Geological Club which was founded at Berkeley on February 4, 1899, and, before the end of the year, became the Cordilleran Section of the Geological Society of America. He was always active in the section and served as its secretary from 1905 to 1914. He was president of the Seismological Society of America for many years and editor of its Bulletin from 1935 onward. From 1920 to 1924 he was a member of the Committee on Sedimentation of the National Research Council. In 1928 he was a member of the California State Commission on the failure of the St. Francis Dam and later served on other state consulting boards on the safety of dams. He was one of the founders of Epsilon Chapter of Theta Tau and always the chief patron of the chapter. From 1919 to 1925 he was Grand Regent of Theta Tau.

In spite of activity in the affairs of many organizations, extensive consulting and heavy administrative duties Professor Louderback managed to maintain an interest in scientific work and in teaching. The chief fields of his scientific interest were basin range structure and west coast stratigraphy, fault lines and earthquakes, but the mineralogical inclination shown by the title of his thesis was not wholly submerged. By far the



GEORGE DAVIS LOUDERBACK

1874-1957

(Photograph taken in Berkeley, 1937)

most important mineralogical episode in Professor Louderback's long career was his description of the rare gem mineral benitoite. The announcement of the discovery of this new mineral was made in July, 1907 (1). Though this was only a brief report it did indicate the extraordinary interest of the newly discovered mineral and the neptunite associated with it. A fuller report was given at the Albuquerque meeting of the Geological Society of America in December, 1907, but only a very short summary of this was printed (2).

The discovery of benitoite aroused great interest and, although Professor Louderback had indicated in the last sentence of his preliminary paper that he expected "shortly to make a more extensive report," nearly a dozen short papers by various authors dealing with benitoite and the San Benito County neptunite appeared before he was able to publish his definitive description. This was delayed almost two and a half years, in part by Professor Louderback's serious illness. The haste with which many had rushed into print deprived the final description of a little novelty but when it did appear it turned out to be a model of what the description of the properties and occurrence of a newly recognized mineral might be and has won for its author the very highest praise (6).

An especially noteworthy feature of Professor Louderback's final report on benitoite (3) was the careful establishment of the symmetry by means of etch figures, since benitoite was the first example of a material crystallized in the ditrigonal-dipyramidal class. When *x*-ray diffraction became available for the study of crystals several mineralogists again turned to the examination of benitoite and in 1930 Zachariasen's determination of the structure in the space group $D_{3h}^2 \cdot P6c2$ supported the conclusion as to symmetry based on etch figures. Only one other material, the artificial germanate analogue of benitoite, is known to crystallize in the same space group.

A rare mineral found with benitoite in minute honey yellow crystals was recognized as new by Professor Louderback. Even though it was not possible to obtain enough for an analysis he reported the results of qualitative chemical tests, gave a careful description of its morphology and optical properties and named it joaquinite (2). Many years later others (4) amplified the description and, establishing the formula $\text{NaBa}(\text{Ti,Fe})\text{Si}_4\text{O}_{15}$, justified the naming of this rare mineral which still awaits detailed study.

The rocks collected by Professor Louderback at the time of his work on benitoite have recently become available for inspection. It is found that he collected many specimens in the vicinity of the Gem mine not referred to in his papers on benitoite. Among these are fine samples of the minerals scattered about in the surrounding serpentine area that

have been eagerly sought of late. Some years ago collectors began to enter the area and to bring out glistening clusters of melanite, adamantinite perovskite and other intriguing things, sometimes keeping the source hidden by false locality designations, but to this day no serious mineralogical study of these deposits has been published (5). Meanwhile the localities are being despoiled by large numbers who now come into this formerly remote area by jeep or jalopy. It seems a pity that Professor Louderback did not turn his superior talents to the study of these most interesting occurrences of calc-silicates and titanium minerals in veins and seams in serpentine and the associated chloritic rocks at a time when they were in a virgin state and all the best material would have been his for the taking.

No doubt his many other activities prevented Professor Louderback from continuing mineralogical studies after his brilliant start on benitoite. Soon thereafter he spent two years as leader of a geological expedition into the interior of China. During the first world war and immediately thereafter he was in charge of work on strategic minerals in California. From 1920 to 1922 and again from 1930 to 1939 he was dean of the College of Letters and Science and from 1925 to 1937 he was chairman of the Department of Geological Sciences. During all of this time he was most effectively active as a teacher of geology and petrology. Among the geologists who began their careers under his guidance may be mentioned E. F. Davis, N. L. Taliaferro, Roy Morse, Frank Hudson, Parker Trask, C. D. Hulin, A. O. Woodford, R. J. Russell, F. A. Moss, V. T. Allen, C. A. Anderson and C. Durrell.

For many years Professor Louderback was the mainstay of instruction in geology at Berkeley, mostly through his graduate courses and seminars. For several decades he conducted a graduate course in petrology in which Rosenbusch-Osann and Grubenmann-Niggli alternated from year to year as textbooks and the students spent many a tedious hour trying to interpret the often tortuous German texts. His methods were strictly those of the "sink or swim" school of instruction and they mostly had the approval of his graduate students who affectionately spoke of him as "the uncle" or "uncle George" but were always respectful in addressing him.

BIBLIOGRAPHY

1. GEORGE D. LOUDERBACK, 1907, Benitoite, a new California gem mineral. (With chemical analysis by Walter C. Blasdale.) *Univ. Calif. Publ., Bull. Dept. Geol.* **5**, 149-153.
2. GEORGE D. LOUDERBACK AND W. C. BLASDALE, 1908, Benitoite: its mineralogy, paragenesis, and geological occurrence. *Bull. Geol. Soc. Amer.*, **19**: 569.
3. GEORGE D. LOUDERBACK, 1909, Benitoite, its paragenesis and mode of occurrence. (With chemical analyses by Walter C. Blasdale.) *Univ. Calif. Publ. Bull. Dept., Geol.* **5**: 331-380.

4. C. PALACHE AND W. F. FOSHAG, 1932, The chemical nature of joaquinite. *Am. Mineral.* **17**, 308-312.
5. A. PABST, 1951, Minerals of the serpentine area in San Benito County, California. *Rocks and Minerals* **26**: 479-485.
6. A. PABST, 1957, George Davis Louderback. *Geochemical News* **8**: 4.

It is expected that a complete bibliography of Professor Louderback's scientific writings will be published in the Bulletin of the Geological Society of America.

MEMORIAL OF ARTHUR LEONARD PARSONS

V. B. MEEN, *Royal Ontario Museum, Toronto, Ontario.*

Arthur Leonard Parsons, former President of our Society, passed away quietly on Sunday, January 6, 1957, at the age of 83. Although he had suffered from a form of heart ailment for more than forty years and had been increasingly frail during the last few years, none the less he was in excellent spirits two days before his passing when he enjoyed a dinner and evening with some close friends.

He was born on September 16, 1873, in Mount Morris, New York, the son of the late Reverend Levi and Mrs. Parsons. After elementary schooling at Mount Morris Union Free School and Academy, he attended New York University, where he received his A.B. degree in 1896. Planning to enter the teaching profession, he attended Geneseo Normal School in 1897 and served as principal of Hinsdale Union School, Hinsdale, New York, in 1897-98.

Then followed a variety of appointments varying from one to two years in length: Inspector of Oils, Olean, New York; Assistant Registrar, New York University; Foote Mineral Company, Philadelphia; Assistant Mineralogist, New York State Museum, Albany, New York; the United States Geological Survey; the Commission on Additional Water Supply, New York City. Although his early life and training had been centered on the Classics, his interests and employment during these later years were changing rapidly toward a major occupation with the subject of mineralogy.

From 1903 to 1907 he served as Instructor in Mineralogy at the University of Minnesota; then, forsaking the land of his birth, he moved with his wife, the former Isabel Louise Smith, and their young daughter, Alice Harriet, to Toronto, Canada, where he took the position of Lecturer in Mineralogy in the University of Toronto. In 1912 he became Assistant Professor of Mineralogy, which title was changed to Associate in 1919 and to Professor of Mineralogy in 1929. He headed the Department from 1936 until his retirement in 1943.

From 1907 to 1920, he served during the summer seasons as field geologist on the staff of the Ontario Bureau (now Department) of Mines. From his investigations in northwestern Ontario forty years ago, he predicted that large iron deposits would be located there. He lived to see this prediction verified in the discovery and development of the deposits at Steep Rock Lake.

In 1920, in addition to his teaching load, he was appointed Assistant Director of the then Royal Ontario Museum of Mineralogy. In association with his chief and colleague, the late Professor T. L. Walker, he



ARTHUR LEONARD PARSONS
1873-1957

(Photograph taken about 1940)

helped build the Museum's mineral collections, now acknowledged to be among the finest in the world. In 1936 he succeeded Professor Walker as Director of the Museum, retiring in 1943.

In his quest for specimens for the collections, he searched Canada from coast to coast and travelled widely in Europe and North America. Always fair in all his dealings, he none the less was happiest when the acquisition of a specimen required a session of horsetrading. His investigations of the minerals and their occurrences resulted in many papers. His special love was crystallography and latterly the hexagonal system took his particular attention. At his death he was compiling a catalogue of the mineral occurrences of Ontario.

He was a Charter Member of the Mineralogical Society of America and served as its President in 1929. In the same year, he served as Vice-president of the Geological Society of America of which he was also a Fellow. He was a Fellow of the Royal Society of Canada, a member of the Mineralogical Society of Great Britain, the Canadian Institute of Mining and Metallurgy; founder, first president and, for many years, Honorary President of the Walker Mineralogical Club. He belonged to the Masonic Order and was a member of University Lodge.

The number of his friends, particularly his former students, seemed almost without limit; and, although his retirement of more than thirteen years had withdrawn him from active association with them, his passing left them a real sense of loss. He is survived by his daughter, Alice Harriet Parsons of Toronto, and a sister, Anne C. Parsons of Mount Morris, New York.

BIBLIOGRAPHY OF ARTHUR LEONARD PARSONS

- Recent Developments in the Gypsum Industry in New York State: *N.Y. State Mus. Ann. Rept.*, **1**, 1902.
- The Gypsum Deposits of New York State: Abstract, *Science*, **19**, 1904.
- Peat: Its Formation, Uses and Occurrence in New York: *N.Y. State Mus. Ann. Rept.*, **1**, 1905.
- Notes on the Gypsum Industry in New York: *N.Y. State Mus. Ann. Rept.*, **1**, 1905.
- Geology of the Thunder Bay-Algoma Boundary: *Ont. Bur. Mines*, **XVII**, 1908.
- The New Sclerometer: *Amer. Jour. Sci.*, **XXIX**, 1910.
- Ein Neues Sklerometer: *Zeit. f. Krystall.*, **XLVII**, 3, 1910.
- (with V. Goldschmidt) Notes on Goethite: *Amer. Jour. Sci.* **XXIX**, 1910.
- (with V. Goldschmidt) Über Goethite: *Zeit. f. Krystall.*, **XLVII**, 1910.
- Gold Fields of Lake of the Woods, Manitou and Dryden: *Ont. Bur. Mines.*, **XX**, 1911.
- Gold Fields of Lake of the Woods, Manitou and Dryden: *Ont. Bur. Mines*, **XXI**, 1912.
- Lake of the Woods and Other Areas: *Ont. Bur. Mines*, **XXII**, 1913.
- Cartier to Coldwell; Coldwell to Port Arthur; Winnipeg to Port Arthur: *Inter. Geol. Cong.*, G.S.C., 1913.
- Michipicoten Iron Ranges: *Ont. Bur. Mines.*, **XXIV**, 1914.
- Hunter Island and Gunflint Lake Iron Deposits: *Ont. Bur. Mines*, **XXV**, 1915.
- Prostitute from Cobalt, Ontario: *Min. Mag.*, 1916.
- Molybdenite Deposits of Ontario: *Ont. Bur. Mines*, **XXVI**, 1917.
- Slate Islands, Lake Superior: *Ont. Bur. Mines*, **XXVII**, 1918.
- (with C. W. Knight, A. G. Burrows and P. E. Hopkins) Abitibi-Night Hawk Area: *Ont. Bur. Mines*, **XXVIII**, 1919.
- Calculation in the Triclinic System, illustrated by Anorthite: *Am. Mineral.*, **5**, 1920.
- Economic Deposits in Thunder Bay District: *Ont. Bur. Mines*, **XXX**, 1921.
- Calcite from Shagoinah Island near Thunder Cape, Lake Superior: *Univ. Tor. Studies*, **12**, 1921.
- (with E. Thomson) Animikite and Macfarlanite from Silver Islet, Thunder Bay, Lake Superior: *Univ. Tor. Studies*, **12**, 1921.
- (with T. L. Walker) Rammelsbergite from Cobalt, Ontario: *Univ. Tor. Studies*, **12**, 1921.
- (with T. L. Walker) The Dehydration of Spencerite: *Univ. Tor. Studies*, **12**, 1921.

(with E. Thomson and T. L. Walker) Notes on Canadian Minerals: *Univ. Tor. Studies*, **12**, 1921.

Polarization Phenomena of Certain Fluorites: *Am. Mineral.*, **7**, 1922.

The Preservation of Mineral Specimens: *Am. Mineral.*, **7**, 1922.

A Third Type of Proustite from Cobalt, Ontario: *Univ. Tor. Studies*, **14**, 1922.

(with T. L. Walker) Tubular Amygdaloid from Nova Scotia: *Univ. Tor. Studies*, **14**, 1922.

(with T. L. Walker) The Zeolites of Nova Scotia: *Univ. Tor. Studies*, **14**, 1922.

(with T. L. Walker) Notes on Some Canadian Diopsides: *Univ. Tor. Studies*, **14**, 1922.

The Formation of Kaolin at Moderate Depths: *Am. Mineral.*, **8**, 1923.

(with T. L. Walker) The North Mountain Basalt of Nova Scotia—Glaciation, Tubular Amygdaloid, Mordenite and Louisite: *Univ. Tor. Studies*, **16**, 1923.

(with T. L. Walker) Ellsworthite and Associated Minerals from Hybla, Ontario: (*Univ. Tor. Studies*, **16**, 1923.

(with T. L. Walker) Hatchettolite and Associated Minerals from Hybla, Ontario: *Univ. Tor. Studies*, **16**, 1923.

(with T. L. Walker) Shattering of Minerals and Rocks about Inclusions: *Univ. Tor. Studies*, **16**, 1923.

(with T. L. Walker) Notes on Canadian Minerals—Allanite, Axinite, Columbite and Sillimanite: *Univ. Tor. Studies*, **16**, 1923.

Xanthoconite from Cobalt, Ontario: *Univ. Tor. Studies*, **17**, 1924.

Pectolite and Apophyllite from Thetford Mines, Quebec: *Univ. Tor. Studies*, **17**, 1924.

(with T. L. Walker) Skutterudite and Loellingite from the LaRose Mine, Cobalt, Ontario: *Univ. Tor. Studies*, **17**, 1924.

(with T. L. Walker) The Arsenates of Cobalt, Nickel and Iron Observed in the Silver-bearing Veins at Cobalt, Ontario: *Univ. Tor. Studies*, **17**, 1924.

(with T. L. Walker) Pegmatite Minerals from New Ross, Nova Scotia: *Univ. Tor. Studies*, **17**, 1924.

Albertite in Gypsum from Hillsboro, New Brunswick: *Univ. Tor. Studies*, **18**, 1925.

(with T. L. Walker) Evanescent Pink Sodalite and Associated Minerals from Dungannon Township, Ontario: *Univ. Tor. Studies*, **20**, 1925.

(with T. L. Walker) The Characteristics of Primary Calcite: *Univ. Tor. Studies*, **20**, 1925.

(with T. L. Walker) Axinite from the Moneta Mine, Timmins, Ontario: *Univ. Tor. Studies*, **20**, 1925.

(with T. L. Walker) Petzite from the Hollinger Gold Mine: *Univ. Tor. Studies*, **20**, 1925.

(with T. L. Walker) The Rate of Oxidation of Arsenides of Iron, Cobalt and Nickel: *Univ. Tor. Studies*, **20**, 1925.

(with T. L. Walker) A Comparison of the Port Arthur, Cobalt, South Lorrain and Gowganda Silver-vein Minerals: *Univ. Tor. Studies*, **20**, 1925.

Additional Data Concerning the Preservation of Minerals: *Am. Mineral.*, **11**, 1926.

(with T. L. Walker) New Localities for Canadian Minerals: *Univ. Tor. Studies*, **22**, 1926.

(with T. L. Walker) Minerals from the New Nepheline Syenite Area, French River, Ontario: *Univ. Tor. Studies*, **22**, 1926.

(with T. L. Walker) Zeolites and Related Minerals from Lake Nipigon, Ontario: *Univ. Tor. Studies*, **22**, 1926.

(with T. L. Walker) Apatite, Lepidomelane and Associated Minerals from Faraday Township, Hastings County, Ontario: *Univ. Tor. Studies*, **22**, 1926.

(with T. L. Walker) Changes in Water Level, and Flotation as Forces of Erosion: *Univ. Tor. Studies*, **22**, 1926.

The Dehydration of Gypsum: *Univ. Tor. Studies*, **24**, 1927.

(with G. Aminoff) Symmetry and Lattice Dimensions of Finnemanite and Nimitite: *Geol. Fören.*, 1927.

- (with G. Aminoff) The Crystal Structure of Sperrylite: *Univ. Tor. Studies*, **27**, 1928.
- (with T. L. Walker) A Re-examination of Bytownite and Huronite: *Univ. Tor. Studies*, **24**, 1927.
- (with T. L. Walker) Beryl and Associated Minerals from Lyndoch Township, Renfrew County, Ontario: *Univ. Tor. Studies*, **24**, 1927.
- (with T. L. Walker) Notes on Canadian Minerals—Tremolite, Clinohumite, Stromeyerite, Natron and Hexahydrite: *Univ. Tor. Studies*, **24**, 1927.
- (with T. L. Walker) The Contact Phenomena of the Nepheline Syenites of Port Coldwell, Ontario: *Univ. Tor. Studies*, **24**, 1927.
- The Determination of the Crystallographic Constants in the Triclinic System: *Am. Mineral.*, **14**, 1929.
- Pyroxene and Scapolite from Templeton Township, Quebec: *Univ. Tor. Studies*, **29**, 1930.
- A Chemical and Optical Study of Amphibole: *Univ. Tor. Studies*, **29**, 1930.
- The Lattice Dimensions of Heulandite from Wasson's Bluff, Nova Scotia: *Univ. Tor. Studies*, **29**, 1930.
- The Lattice Dimensions of Natrolite from Wasson's Bluff, Nova Scotia, *Univ. Tor. Studies*, **29**, 1930.
- (with T. L. Walker) Notes on Minerals—Calamine, Galena, Magnetite: *Univ. Tor. Studies*, **29**, 1930.
- Iridescent Color in Peristerite: *Am. Mineral.*, **15**, 1930.
- The Mode of Occurrence of the Giant Zircons from Brudenell Township, Ontario: *Univ. Tor. Studies*, **30**, 1931.
- The Effect of Twin Lamellae on the Interference Colours of Dolomite: *Univ. Tor. Studies*, **30**, 1931.
- (with G. Greenwood) The Lattice Dimensions of Certain Monoclinic Amphiboles: *Univ. Tor. Studies*, **30**, 1931.
- Crystal Habit of Uraninite from Cardiff Township, Ontario: *Univ. Tor. Studies*, **32**, 1932.
- Zircon From Cardiff Township, Ontario: *Univ. Tor. Studies*, **32**, 1932.
- Twinned Beryl from Lyndoch Township, Ontario: *Univ. Tor. Studies*, **32**, 1932.
- Two New Types of Interpenetration Twins on Gypsum: *Univ. Tor. Studies*, **32**, 1932.
- The Errington Diamond: *Univ. Tor. Studies*, **35**, 1933.
- A Simple and Inexpensive Projection Sheet for Gnomonic and Stereographic Projections, *Am. Mineral.*, **19**, 1934.
- The Utilization of the Semi-precious and Ornamental Stones of Canada: *Univ. Tor. Studies*, **36**, 1934.
- An Unusual Calcite Crystal from Godfrey, Ontario: *Univ. Tor. Studies*, **36**, 1934.
- Linear Mineralogical Arithmetic: *Am. Mineral.*, **20**, 1935.
- Trisectahedral Garnet from West Thetford Mines, P. Q.: *Univ. Tor. Studies*, **38**, 1935.
- (with T. L. Walker) The Royal Ontario Museum of Mineralogy: *Museums Journal*, **35**, 1936.
- Two-Circle Calculation in the Hexagonal System: *Am. Mineral.*, **22**, 1937.
- Additional Semi-precious and Ornamental Stones of Canada: *Univ. Tor. Studies*, **41**, 1938.
- Wave-surfaces and Indicatrices (Abstract): *Am. Mineral.*, **23**, 1938.
- Magnesiochromite from Caribou Pit, Coleraine Township, Quebec: *Univ. Tor. Studies*, **42**, 1939.
- Memorial of Thomas Leonard Walker: *Washington Acad. Sci. Journal*, **33**, 1943.
- Memorial of Thomas Leonard Walker: *Am. Mineral.*, **28**, 1943.
- Memorial of Joseph Ellis Thomson: *Am. Mineral.*, **30**, 1945.
- Gnomonic and Linear Heptaxial Two-Circle Calculation: *Am. Mineral.*, **31**, 1946.
- Hexagonal Zonal Equations (Abstract): *Am. Mineral.*, **33**, 1948.

MEMORIAL OF JOHN CHARLES RABBITT

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John Charles Rabbitt died suddenly at his home in Washington, D. C. on the evening of June 10, 1957. He was working on an overtime load of office papers, as was his custom, when stricken by a fatal coronary occlusion.

Jack Rabbitt (a name he relished and was known by universally) was born November 3, 1907 in Butte, Montana. He was the son of Grace Esther (Decker) and Thomas Rabbitt. His father died when Jack was seven, leaving his mother with three growing sons and little worldly goods. After finishing high school, he worked as a miner in Butte for about six years. It was characteristic of Jack that this became a profound and lasting experience. He learned much about the history and practice of mining and a great deal of Irish history and lore. He acquired deep respect for the common man and a compassionate understanding of the problems of minority and immigrant groups. He also saw the advantages of further education. He entered the Montana School of Mines from which he received the Bachelor's degree in geology in 1935, and the Master's degree in paleontology in 1937. He continued his geologic studies at Harvard University where he was particularly influenced by the late Harry Berman, by Clifford Frondel, and by Esper S. Larsen, Jr. He received his doctorate in petrology and mineralogy from Harvard in 1947.

He was appointed a geologist with the U. S. Geological Survey in 1942 and continued there until his death. During the World War II years, using spectrographic facilities made available at Harvard, he analyzed many thousands of mine, mill, and smelter products for a large group of critically short elements, including uranium.

In 1947 he was given the responsibility of establishing and operating the extensive laboratory facilities needed to support the Survey's uranium resources program being undertaken for the U. S. Atomic Energy Commission. Within a year he had in operation what soon became probably the largest and best equipped mineralogical-geochemical laboratory in the world. His personal leadership of a professional staff of nearly 100 was, I believe, his greatest contribution to geology. His guidance, advice, and encouragement developed many sound scientists from professionally inexperienced young graduates, and the laboratory he initiated and led contributed fundamentally to many fields of geology and geochemistry.

In 1953 Jack was assigned to the staff of the Chief Geologist. For a year he served as Assistant Chief Geologist. He became vitally interested in the Survey's publication program and was made responsible for re-



JOHN CHARLES RABBITT
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organizing that program in the Chief Geologist's office; he was deeply engrossed in this administrative duty at the time of his death.

In 1947 Jack married Mary Priscilla Collins, who had been a research assistant in geophysics at Harvard during his years there. They were an exceptionally happy couple with both professional and cultural interests in common. They were extraordinarily well read and well informed. Both loved the theatre, music, and the ballet. They enjoyed entertaining small groups of their intimate friends, and at such times it was easy to start Jack reminiscing about his mining days at Butte, or his grandfather's saloon in Chicago; or to start an argument on any political subject, the Irish-English controversy (Jack's mother was of German descent, but

Jack was pure Irish), or the ideal laboratory program to support the Survey's study of uranium resources.

Jack's interest in people led him early into administrative work. Although his bibliography is short he was a sound scientist, as demonstrated by his profound work on anthophyllite. He contributed much more through his encouragement of the work of others.

He is survived by his widow, who continues her professional career as a geologist with the U. S. Geological Survey. He is survived, too, by his brothers, Thomas, of Seattle, Washington, and Francis, of Houston, Texas.

Many people respected and loved Jack. He is sorely missed.

BIBLIOGRAPHY OF JOHN CHARLES RABBITT

(with Marland P. Billings). Chemical analyses and calculated modes of the Oliverian magma series, Mt. Washington quadrangle, New Hampshire: *Geol. Soc. America Bull.*, **58**, 573-596, 1947.

A new study of the anthophyllite series: *Am. Mineral.*, **33**, 263-323, 1948.

"The Professor": *Am. Mineral.*, **35**, 619-621, 1950.

(with Michael Fleischer). Geochemistry in *Annual Review of Nuclear Science*, **1**, 465-478, 1952.

(with E. P. Kaiser and B. F. Herring). Minor elements in some rocks, ores, and mill and smelter products: 119 p., *U. S. Geol. Survey TEI-415*, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn., 1954.

(with Mary C. Rabbitt). The U. S. Geological Survey, 75 years of service to the nation, 1879-1954: *Science*, **119**, 741-758, 1954.

MEMORIAL OF AUSTIN FLINT ROGERS

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Austin Flint Rogers died on March 10, 1957 in Berkeley, California, a few months short of his eightieth birthday. He was one of the founders of the Mineralogical Society of America and in 1927 was elected president. He stood for many years as one of the leaders in a group of senior scientists who were instrumental in establishing mineralogy as a science in North America.

Professor Rogers' scientific activity began in Missouri and Kansas, covered a moderate period in New York, and throughout a large part of his career centered in California. He was born in Lathrop, Missouri, August 15, 1877. While a student in the Central High School in Kansas City, a chemistry teacher encouraged his interest in natural science, and the collection of minerals and fossils from the quarries in the vicinity became a serious hobby. Dr. Rogers attended the Missouri School of Mines for one year and then transferred to the University of Kansas where he received the A.B. degree in 1899 and the A.M. degree a year later. In 1901 he was awarded a fellowship at Columbia University where he studied in the Department of Mineralogy with Professors Alfred J. Moses and Lea M. Luquer. The Ph.D. degree at Columbia University was awarded to Professor Rogers in 1902.

It was at this time that Dr. David Starr Jordan, then President of Stanford University, was looking for a young man to initiate the study of mineralogy at the youthful university President Jordan had been building academically in California. Through his friendship with Dr. Nicholas Murray Butler, President of Columbia University, his attention became focused on a young doctorate recipient at Columbia, Austin Rogers. In 1902 Dr. Rogers began a career at Stanford University, where over the years geologists on the Pacific Coast came to look with respect on the famous staff of Stanford geologists which, along with Professor Rogers, included Professors John Casper Branner, James Perrin Smith and Cyrus Fisher Tolman.

The teaching contribution that Dr. Rogers made at Stanford University covered a span of forty years. During that time no student graduated from Stanford without having taken at least the Introduction to Mineralogy course. The interest a few had developed in the subject as undergraduates led them to continue as graduate students. Students from other universities were also attracted to the Stanford group and came for graduate training. Several doctorate degrees in mineralogy from Stanford University were achieved in this way (including the writer's). These men comprised a nucleus of enthusiastic mineralogists who joined



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the faculties of other universities and carried on the teaching and scientific work that Professor Rogers had so ably demonstrated to them in their student days.

In the field of mineralogical research, Dr. Rogers showed an inquiring mind which led beyond mineralogical techniques toward a better understanding of the physical and chemical environment under which minerals grow. He became an authority in several fields of mineralogy. His work on magmatic sulfide minerals written with Professor Tolman still stands after many years as a major fundamental contribution to the subject. His contributions to the mineralogy of phosphate minerals are among the most authoritative publications on the subject. He was keenly interested in the way minerals form and devoted a large amount of time to field collection followed by microscopic study. The breadth of this interest is well shown by the variety of minerals and mineral groups in the appended bibliography of 99 titles.

Those who saw Professor Rogers only in the classroom missed the rare opportunity of watching him as he proved his capabilities in other activities. One hobby was culinary. Looking back on student days at Stanford, the writer well remembers a memorable Thanksgiving Day dinner which included a nicely browned turkey and all of the trimmings cooked, arranged and served by Dr. Rogers himself.

In his later years Professor Rogers became interested in gems. A discovery of jade in California led to his enthusiasm for the subject, reflected in the assembly of a small gem collection; a popular lecture series was also inaugurated. The proceeds from these lectures were contributed to Chinese relief during the second world war.

In true mineralogical tradition, Professor Rogers discovered and named several new minerals. In recognition of his old friend of student days, he named one mineral *kempite* in honor of James Furman Kemp, for many years professor of economic geology at Columbia University. Other new minerals that he discovered were named sanbornite, wilkeite and cornuite. Rogersite and austinite were named by others in his honor.

The educational influence of Dr. Rogers extended far beyond Stanford University. His textbook, written as an introduction to mineralogy, is accurate, concise, informative and has been widely used. The optical descriptions of minerals in the textbook "Optical Mineralogy" originally prepared by Professor Rogers as the second half of a book written jointly with the author have been used on a worldwide basis. His guidance was valued by the Mineralogical Society of America where he served as an Associate Editor of the *American Mineralogist* for many years. In 1930, Stanford University created the Austin F. Rogers Teaching Fellowship in Mineralogy in recognition of his interest in the science.

Professor Rogers received the Erasmus Haworth Award conferred on distinguished alumni by the University of Kansas in 1950. He was elected a fellow of the American Academy of Arts and Sciences. In addition to being a charter fellow of the Mineralogical Society of America, he was a fellow of the Geological Society of America. He was a member of the Mineralogical Society of Great Britain and the Société française de Mineralogie.

Throughout his academic career, Dr. Rogers constantly maintained a high standard of achievement and was particularly objective in appraising not only the work of his students but his own work as well. He formed a strong attachment for many students, but personal preference was no substitute for demonstrated performance when term marks were prepared.

Dr. Rogers, who was married in 1902, is survived by a daughter, Genevieve and a son, Ronald. His retirement from Stanford University in 1942 did not mean the end of his career. On the contrary, he continued to promote interest in mineralogy by delivering lectures on gem stones until the time of his final illness.

All who had the good fortune to be associated with Professor Rogers are grateful for the experience of having known one of the great contributors to American mineralogy.

SELECTED BIBLIOGRAPHY OF AUSTIN F. ROGERS

- Cupro-goslarite, a new variety of zinc sulphate: *Kansas. Univ. Quart.*, **8**, 105-106 (1899).
 Normal ankerite from Phelps Co., Missouri: *Kans. Univ. Quart.*, **8**, 183 (1899).
 Sphalerite crystals of a peculiar habit and with one new form, from Galena, Kansas: *Am. Jour. Sci.*, 4th ser., **9**, 134-136 (1900).
 Annotated list of the minerals occurring in the Joplin lead and zinc district: *Kans. Univ. Quart.*, **9**, 161-165 (1900).
 The Pottawatomie and Douglas formations along the Kansas River: *Kans. Univ. Quart.*, **9**, 234-254 (1900).
 (with J. W. Beede), Coal Measures faunal studies: *Kans. Univ. Quart.*, **9**, 233-254 (1900); *Kans. Univ. Sci. Bull.*, **1**, 163-181 (1902); **2**, 459-473 (1904); **3**, 377-388 (1906).
 A list of the crystal forms of calcite with their interfacial angles: *Sch. Mines Quart.*, **22**, 429-448 (1901).
 A list of minerals arranged according to the thirty-two crystal classes: *Sch. Mines Quart.*, **23**, 79-98 (1901).
 The crystallography of the calcites of the New Jersey trap region: *Sch. Mines Quart.*, **23**, 336-347 (1902).
 New graphical methods in crystallography: *Sch. Mines Quart.*, **23**, 67-72 (1902).
 (with A. J. Moses), Formulae and graphic methods for determining crystals in terms of coordinate angles and Miller indices: *Sch. Mines Quart.*, **24**, 1-36 (1902).
 Ein neuer Transporteur zur Bestimmung der Indices der Kry stallflächen: *Zeits. Kryst.*, **38**, 491-494 (1903).
 (with A. J. Moses), Formeln und graphische Methoden zur Bestimmung von Krystallen

- auf Grund von Koordinatenwinkeln und Miller'schen Indices: *Zeits. Kryst.*, **38**, 209–226 (1903).
- A method for the exact expression of crystal habit: *Sch. Mines Quart.*, **25**, 199–203 (1904).
- Minerals of the Galena-Joplin lead and zinc district: *Kans. Univ. Geol. Surv.*, **8**, 445–509 (1904).
- The determination of minerals in crushed fragments by means of the polarizing microscope: *Sch. Mines Quart.*, **27**, 340–359 (1906).
- Some points in teaching crystallography: *Science*, **24**, 620–621 (1906).
- (with J. W. Beede), Coal Measures faunal studies, IV, Upper Coal Measures, Neosho River section: *Kans. Univ. Sci. Bull.*, **3**, 375–388 (1906).
- Stöber's method of making crystal drawings: *Sch. Mines Quart.*, **38**, 222–225 (1907).
- The gnomonic projection from a graphical standpoint: *Sch. Mines Quart.*, **29**, 24–33 (1907).
- Aegirite and riebeckite rocks from Oklahoma: *Jour. Geol.*, **15**, 283–287 (1907).
- A simple reflection goniometer: *Science*, **27**, 929–930 (1908).
- Note on the crystal form of benitoite: *Science*, **28**, 616 (1908).
- (with J. W. Beede), Coal Measures faunal studies; Faunal divisions of the Kansas Coal Measures: *Kans. Univ. Geol. Surv.*, **9**, 318–385 (1908).
- Pyrite crystals from Bingham, Utah: *Am. Jour. Sci.*, 4th ser., **27**, 467–468 (1909).
- Notes on some pseudomorphs, petrifications, and alterations: *Am. Phil. Soc. Proc.*, **49**, 17–23 (1910).
- Anhydrite and associated minerals from the salt mines of central Kansas: *Am. Jour. Sci.*, 4th ser., **29**, 258–261 (1910).
- Minerals from the pegmatite veins of Rincon, San Diego Co., California: *Sch. Mines Quart.*, **31**, 208–218 (1910).
- The study of rocks without the use of the microscope: *Science*, **31**, 739–740 (1910).
- A new synthesis and new occurrences of covellite: *Sch. Mines Quart.*, **32**, 298–304 (1911).
- Eglestonite from San Mateo Co., California: *Am. Jour. Sci.*, 4th ser., **32**, 48–50 (1911).
- On corundum syenite (uralose) from Montana: *Jour. Geol.*, **19**, 748–751 (1911).
- Orthoclase-bearing veins from Rawhide, Nevada, and Weehawken, New Jersey: *Econ. Geol.*, **6**, 790–798 (1911).
- Introduction to the study of minerals; a combined textbook and pocket manual: McGraw-Hill Book Co., Inc., 522 pp. (1912); revised edition: 527 pp. (1921).
- Baddeleyite from Montana: *Am. Jour. Sci.*, 4th ser., **33**, 54–56 (1912).
- Lorandite from the Rambler mine, Wyoming: *Am. Jour. Sci.*, 4th ser., **33**, 105–106 (1912).
- The occurrence and origin of gypsum and anhydrite at the Ludwig mine, Lyon Co., Nevada: *Econ. Geol.*, **7**, 185–189 (1912).
- Dahlite (podolite) from Tonopah, Nevada; voelckerite, a new basic calcium phosphate; remarks on the chemical composition of apatite and phosphate rock: *Am. Jour. Sci.*, 4th ser., **33**, 475–482 (1921); *Zeits. Kryst.*, **52**, 209–217 (1913).
- The paragenesis of minerals: *Econ. Geol.*, **7**, 638–646 (1912).
- Notes on rare minerals from California: *Sch. Mines Quart.*, **33**, 373–381 (1912).
- Delafossite, a cuprous metaferriite from Bisbee, Arizona: *Am. Jour. Sci.*, 4th ser., **35**, 290–294 (1913).
- Observations on the feldspars: *Jour. Geol.*, **21**, 202–207 (1913).
- The nomenclature of minerals: *Am. Phil. Soc. Proc.*, **52**, 606–615 (1913).
- Upward secondary sulphide enrichment and chalcocite formation at Butte, Montana: *Econ. Geol.*, **8**, 781–794 (1913).
- Secondary sulphide enrichment of copper ores with special reference to microscopic study: *Min. Sci. Press*, **109**, 680–686 (1914).

- (with A. S. Eakle), Wilkeite, a new mineral of the apatite group, and okenite its alteration product, from southern California: *Am. Jour. Sci.*, 4th ser., **37**, 262-267 (1914).
- (with H. W. Turner), A geologic and microscopic study of a magmatic copper sulphide deposit in Plumas Co., California, and its modification by ascending secondary enrichment. *Econ. Geol.*, **9**, 359-391 (1914).
- A new locality for voelckerite [Santa Clara Co., California] and the validity of voelckerite as a mineral species: *Mineral. Mag.*, **17**, 155-162 (1914).
- Lawsonite from the central Coast Ranges of California: *Am. Jour. Sci.*, 4th ser., **39**, 105-112 (1915).
- Notes on the occurrence of anhydrite in the United States: *Sch. Mines Quart.*, **36**, 123-142 (1915).
- The study of ores at Stanford: Geol. and Mining Soc., *Am. Univ., Yr. Bk.*, **2**, 20-24 (1915).
- Origin of copper ores of the "red beds" type: *Econ. Geol.*, **11**, 366-380 (1916).
- The so-called graphic intergrowth of bornite and chalcocite: *Econ. Geol.*, **11**, 582-593 (1916).
- (with C. F. Tolman, Jr.), A study of the magmatic sulfide ores: *Leland Stanford Junior Pub., Univ. Ser.*, 76 pp. (1916).
- A review of the amorphous minerals: *Jour. Geol.*, **25**, 515-541 (1917).
- (with C. F. Tolman, Jr.), The origin of the Sudbury nickel ores: *Eng. Min. Jour.*, **103**, 226-229 (1917).
- The occurrence of cristobalite in California: *Am. Jour. Sci.*, 4th ser., **45**, 222-226 (1918).
- An American occurrence of periclase and its bearing on the origin and history of calcite-brucite rocks: *Am. Jour. Sci.*, 4th ser., **46**, 581-586 (1918).
- Colemanite pseudomorphous after inyoite from Death Valley, California: *Am. Mineral.*, **4**, 135-139 (1919).
- An interesting occurrence of manganese minerals near San Jose, California: *Am. Jour. Sci.*, 4th ser., **48**, 443-49 (1919).
- Delafossite from Kimberly, Nevada; *Am. Mineral.*, **7**, 102-103 (1922).
- The optical properties and morphology of bisbeeite: *Am. Mineral.*, **7**, 153-154 (1922).
- Collophane, a much neglected mineral: *Am. Jour. Sci.*, 5th ser., **3**, 269-276 (1922).
- A new occurrence of cristobalite in California: *Jour. Geol.*, **30**, no. 3, 211-216 (1922).
- *Cristobalite in the spherulitic obsidian from Yellowstone National Park: *Am. Mineral.*, **6**, 4-6 (1921).
- Euhedral magnesite crystals from San Jose, California: *Am. Mineral.*, **8**, 138-140 (1923).
- The use of plans and elevations in the study of geometrical crystallography: *Am. Mineral.*, **8**, 19-31 (1923).
- The crystallography of hydromagnesite: *Am. Jour. Sci.*, 5th ser., **6**, 37-47 (1923).
- Clinzoisite from Lower California: *Am. Mineral.*, **9**, 221-224 (1924).
- Kempite, a new manganese mineral from California: *Am. Jour. Sci.*, 5th ser., **8**, 145-150 (1924).
- The crystallography of searlesite: *Am. Jour. Sci.*, 5th ser., **7**, 498-502 (1924).
- Mineralogy and petrography of fossil bone: *Bull. Geol. Soc. Am.*, **35**, no. 3, 535-556 (1924).
- Friedel's law of rational symmetric intercepts; with bibliography of irrational three fold axis of symmetry: *Am. Mineral.*, **10**, 181-187 (1925).
- The addition and subtraction rule in geometrical crystallography: *Am. Mineral.*, **11**, 303-315 (1926).
- Sand calcite crystals from Monterey County, California: *Am. Mineral.*, **11**, 23-28 (1926).
- A mathematical study of crystal symmetry: *Am. Acad. Arts and Sci. Proc.*, **61**, no. 7, 161-203 (1926).

- Natural history of the silica minerals: *Am. Mineral.*, **13**, 73-92 (1928).
A tabulation of the 32 crystal classes: *Am. Mineral.*, **13**, 571-577 (1928).
Periclase from Crestmore near Riverside, California, with a list of minerals from this locality: *Am. Mineral.*, **14**, 462-469 (1929).
Polysynthetic twinning in dolomite: *Am. Mineral.*, **14**, 245-250 (1929).
A unique occurrences of lechatelierite or silica glass: *Am. Jour. Sci.*, 5th ser., **19**, 195-202 (1930).
Castanite, a basic ferric sulphate from Knoxville, California: *Am. Mineral.*, **16**, 396-404 (1931).
Sanbornite, a new barium silicate from Mariposa County, California: *Am. Mineral.*, **17**, 161-172 (1932).
Structural crystallography: *Am. Mineral.*, **18**, 538-542 (1933).
A model for biaxial crystals: *Am. Mineral.*, **19**, 206-208 (1934).
The chemical formula and crystal system of alleghanyite: *Am. Mineral.*, **20**, 25-35 (1935).
A tabulation of crystal forms and discussion of form-names: *Am. Mineral.*, **20**, 838-851 (1935).
Precious stones; *Mineralogist*, **3**, no. 11, 3-4; 27-29 (1935).
Introduction to the study of Minerals: McGraw Hill Bk. Co., Inc., 3rd ed., 626 pp. (1937).
Lapis lazuli from San Bernardino County, California: *Am. Mineral.*, **23**, 111-114 (1938).
Fossil termite pellets in opalized wood from Santa Maria, California: *Am. Jour. Sci.*, 5th ser., **86**, no. 215, 389-392 (1938).
Lamprobolite, a new name for basaltic hornblende: *Am. Mineral.*, **25**, 826-828 (1940).
(with Paul F. Kerr), Optical Mineralogy: McGraw Hill Bk. Co., Inc., 2nd ed., 390 pp. (1942). Published in 1933, 1st ed., as Thin-section Mineralogy.
Pellet phosphorite from Carmel Valley, Monterey County, California: *Calif. Jour. Mines and Geol.*, **40**, 4, 411-421 (1944).
Physical axes of reference and geometrical axes of reference for quartz: *Am. Jour. Sci.*, **243**, no. 7, 384-392 (1945).
Sand fulgurites with enclosed lechatelierite from Riverside County, California: *Jour. Geol.*, **54**, no. 2, 117-122 (1946).
Braunite from Snowmass, Pitkin County: *Am. Mineral.*, **31**, 561-568 (1946).
Uraninite crystals with a new form, from Portland, Connecticut: *Am. Mineral.*, **32**, 83-89 (1947).
Uraninite and pitchblende: *Am. Mineral.*, **32**, 90-91 (1947).

MEMORIAL OF SAMUEL JAMES SHAND

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Samuel James Shand was born in Edinburgh in 1882 and died at Broughty Ferry, near Dundee, in April of 1957. It was at the Dundee branch of St. Andrews that his geological education began, and it was to the same institution that he returned, in a more or less unofficial capacity, a few years before his death. At college his first interest was chemistry, which he studied under James Walker. To this he soon added an avid curiosity about geology, a curiosity so strong that it prompted him, in concert with a number of fellow students, to petition the school for instruction in that subject. Graduating in 1905, he went from St. Andrews to Münster, where he studied under Karl Busz during 1905-06, doing a Ph.D. dissertation on the alkaline rocks of Åssynt, with particular emphasis on the curious pseudo-leucite or quasi-pseudo-leucite called borolanite. In 1910 he received the D.Sc. from St. Andrews.

On leaving Münster he served briefly as lecturer in geology at Dundee and St. Andrews, and in 1907 became an assistant keeper in the Royal Scottish Museum. In 1911 he left the Museum, his last employment in his native land, to take the chair of geology at Stellenbosch, South Africa. Here for the first few years he was the whole department, and for a quarter of a century he was its mainstay and chief inspiration. He was always proud of the department he built at Stellenbosch, and of his influence on the study of geology in South Africa. During the first world war he served as a water supply officer in Mesopotamia and at the close of the war he worked briefly on the petrography of the reservoir limestones of the Iranian oil field. This was his only extended absence from Stellenbosch until he came to Columbia as Professor of Petrology in the spring of 1937. At Columbia he had just about reorganized things to his taste and was ready for serious scientific and educational activity when the war pretty well terminated the possibility that he could concentrate on either. Both the war itself and his own sense of helplessness in relation to it disturbed him immensely. He was further and irretrievably depressed by the death of his wife in 1947, and in 1950, against the wishes and advice of some of his colleagues, he retired from Columbia to spend the rest of his life in Scotland.

As soon as he could find quarters he took up residence in Edinburgh, where he spent considerable time assisting in the reorganization of some of the same Museum collections he had worked on during his tenure as assistant keeper, more than 40 years before. He later moved back to his childhood home, Broughty Ferry, and prior to his final illness engaged



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himself in a continuation of the same campaign which had given him such pleasure as a student, viz. the struggle—and to him it did seem a struggle—to broaden and improve the geological curriculum at the Dundee branch of St. Andrews.

A Fellow of our Society, the Mineralogical Society of London, the Royal Society of Edinburgh, the Geological Societies of London, America and South Africa, he was president of the Geological Society of South Africa in 1923 and a Councillor of our Society in 1944-47. An honorary member of the Geological Society of Belgium, he was awarded the Draper Memorial Medal of the Geological Society of South Africa and the Lydell Medal of the Geological Society of London.

The interests and attitudes which characterize most of his professional work are already clearly apparent in his first papers on Assynt. He had a sure touch for descriptive petrography, an almost devout love of minerals and rocks, particularly of the alkaline rocks and the minerals of which they are composed, an acute sense of the importance of good chemical analyses of rocks and minerals, a remarkable ability to organize and systematize, a graceful and penetrating skill at polemic, an immediate, charming, and sometimes disarming, willingness to confess the limits of his own knowledge.

His papers on Assynt were followed by a succession of field studies of the alkaline massifs of South Africa. He corresponded widely with other students of the alkaline rocks, built up an extensive collection of analyzed and type-locality specimens from all over the world, and developed a truly remarkable erudition on the subject. His concentration on these relatively rare rocks was one of his own favorite examples of the horrors of overspecialization; he often wondered what was to become of petrology, let alone geology, when a man working as diligently as he was unable to keep abreast of publications concerning only this one small area of inquiry. He was an early and outspoken supporter of Daly's limestone-assimilation hypothesis, and his doughty arguments in support of it are among his best known essays.

His interest in chemistry, chemical analysis and rock classification, so strongly foreshadowed in the Assynt papers, soon found expression in journal articles devoted to principles upon which a sound chemical-mineralogical classification might be constructed. The system he finally developed formed the backbone of his major work, *Eruptive Rocks*, an invaluable text which can be read with as much pleasure as profit. Appearing first in 1927, it went through four editions, the last appearing in 1951, and continues to exert a powerful and salutary influence on the study and teaching of petrology.

Most of Shand's professional effort was devoted to his text and his

studies of alkaline rocks, but he also made notable contributions in other fields. It was he who first discovered and named pseudotachylyte. He also developed the first practical instrument for modal analysis, for the modern line integrators are all lineal descendants of the Shand stage. He improved and publicized staining techniques for the feldspathoids. His *Earthlore; Geology without Jargon*, though now rather dated, is a model of the clarity, simplicity and integrity essential to the successful popularization of science. *Useful Aspects of Geology* and *Rocks for Chemists*, the latter of which was written in retirement, attempt to do for a professional audience what *Geology without Jargon* attempted to do for the alert non-scientist.

In personal life Shand was retiring to the point of withdrawal. He read widely, and one of the few things he appreciated about life in New York was the opportunity it afforded for theater-going. Though he may never have managed to complete his collection of reprints on alkaline rocks, there was hardly a foreign movie he failed to see. He studied Gaelic for a number of years and was a convinced Scottish Nationalist. In religious matters he was a conscientious and forthright skeptic; he always considered it desirable to combat fundamentalism and orthodoxy wherever and whenever he came in contact with them. But he was not without his own prejudices, and though he never allowed these to interfere with his teaching, his attitude toward them was curiously ambivalent; perhaps the best way to characterize it is to say that he tended to be apologetic about his acknowledged self-righteousness.

Although during my years in his laboratory I was continually aware of receiving expert and masterful instruction, I know nothing of his teaching methods. I think he would have denied there was such a thing as a method of teaching separable from subject matter. Staring out of the laboratory window at the great pile of Teacher's College one day, he remarked rather fiercely to me that, since teaching was the second oldest profession, the demonstration of a need for more than rudimentary instruction in it would raise serious doubts about the educability of the race. He never doubted the educability of the race.

By standards current at that time his pedagogy was, to say the least, unusual. His lectures conveyed the same sense of easy but acute organization one finds in his publications, but he regarded attendance at them as a matter of little or no consequence for the student. There was no assigned text for any course he gave, and although he suggested much supplementary reading, his own book rarely appeared on the reserve shelf in the reading room. In some semesters, in fact, a student could go right through the course without learning that the lecturer was the author of one of the best books on the subject. I do not think he placed much weight on the result of any formal examination. He considered laboratory

sessions of the utmost importance and always conducted them himself. His judgements of students were evidently based largely on casual conversation and observation during the long afternoons over the microscope.

His own interest in rocks was intense and complete but he never made any overt move to attract—or even to hold—students. For casual or disinterested students I think he was in fact a rather indifferent instructor. As a university teacher he simply had no interest in those who were not interested in his subject. But he always more than matched any genuine interest whatever the status or training of the student who displayed it. And if he discovered that you wanted to “do” petrology, or even had reason to suppose you were somewhat “on the petrologic side,” you became a member of a small club upon whose members he lavished an amount of personal attention and instruction rare in any school.

Anyone familiar with the uneven character of American undergraduate instruction in geology at that time would have had serious reservations about the effectiveness of such an attitude. How could students, most of whom had barely heard of his subject, take in it the kind of interest he demanded as a prerequisite for his interest in them? It was useless for those of us who worked under him to remonstrate with him on this score, and I imagine his fellow faculty members had much the same experience. A thoughtful educator of long experience, he felt that a university should be a community of scholars, that scholars knew what they wanted to study, that those who wished to study together would do so, and that his principal, if not quite his only responsibility, was to those who knew they wanted to study with him. This responsibility he always met, at whatever cost in time and effort.

BIBLIOGRAPHY OF S. JAMES SHAND

MARJORIE HOOKER

Über Borolanit und die Gesteine des Cnoc-na-Sroine-Massivs in Nord-Schottland: *Neues Jahrb. Miner. Geol. Paläon. Beilage-Band* 22, 413–453, 1906.

Note upon crystals of grossularite from Corsiehill quarry: *Perthshire Soc. Nat. Science Trans.* 4, 210–212, 1908.

An introduction to petrography and guide to the collections of rocks (Royal Scottish Museum). 50 p., printed by Morrison and Gibb, Ltd., for H. M. Stationery Office, Edinburgh, 1909.

On borolanite and its associates in Assynt (preliminary communication): *Edinburgh Geol. Soc. Trans.* 9, 202–215, 1909; (second communication), 9, 376–416, 1910.

A Guide to the Scottish mineral collection (Royal Scottish Museum). 36 p., printed by Morrison and Gibb, Ltd., for H. M. Stationery Office, Edinburgh, 1910.

On a group of minerals formed by the combustion of pyritous shales in Midlothian: *Miner. Mag.* 15, 403–406, 1910.

Some Scottish granite-gneiss contacts and their interpretation: *Edinburgh Geol. Soc. Trans.* 9, 365–375, 1910.

- An introduction to the study of crystals and guide to the crystal collection (Royal Scottish Museum). 45 p., printed by Morrison and Gibb, Ltd., for H. M. Stationery Office, Edinburgh, 1912.
- On saturated and unsaturated igneous rocks: *Geol. Mag.* (5) **10**, 508–514, 1913.
- On veins and inclusions in the Stellenbosch granite: *South African Jour. Science*, **9**, 247–251, 1913.
- The terraces of Eerste River at Stellenbosch: *Geol. Soc. South Africa Trans.* **16**, 147–155, 1914.
- The principle of saturation in petrography: *Geol. Mag.* (6) **1**, 485–493, 1914.
- On tachylyte veins and assimilation phenomena in the granite of Parijs (Orange Free State) (abstract): *Geol. Soc. London, Abs., Proc.* 1914–1915, no. **964**, 10–11, 1914. Later withdrawn by the author.
- On the occurrence of the Brazilian trilobite *Pennaia* in the Bokkeveld beds: *Geol. Soc. South Africa Trans.* **17**, 24–28, 1915.
- The principle of saturation in petrography, a reply: *Geol. Mag.* (6) **2**, 339–340, 1915.
- The alkaline rocks of South West Africa: *Geol. Mag.* (6) **2**, 575–576, 1915.
- A recording micrometer for geometrical rock analysis: *Jour. Geology*, **24**, 394–404, 1916.
- The intrusions in the granite of Parys, Orange Free State (abstract): *South African Jour. Science* **12**, 722, 1916.
- The geology of the neighbourhood of Stellenbosch: *South African Jour. Science* **14**, 124–136, 1917.
- The pseudotachylyte of Parijs (Orange Free State), and its relation to ‘trap-shotten gneiss’ and ‘flinty crush-rock’: *Geol. Soc. London, Quar. Jour.* **72**, 198–221, 1917; abstract, *Abs. Proc.* 1915–1916, no. **989**, 52, 1916.
- A system of petrography: *Geol. Mag.* (6) **4**, 463–469, 1917.
- The norite of the Sierra Leone: *Geol. Mag.* (6) **5**, 21–23, 1918.
- A rift-valley in western Persia: *Geol. Soc. London, Quar. Jour.* **75**, 245–250, 1920; discussion and reply, *Abs. Proc.* 1918–1919, no. **1046**, 18–20, 1919.
- Sketches from South African geology (abstract): *Edinburgh Geol. Soc. Trans.* **11**, 112–113, 1920.
- The nomenclature of petrology: *Geol. Mag.* **58**, 191–192, 1921.
- The igneous complex of Leeuwfontein, Pretoria district: *Geol. Soc. South Africa Trans.* **24**, 232–249, 1922.
- The nepheline rocks of Sekukuniland: *Geol. Soc. South Africa Trans.* **24**, 111–149, 1922.
- The alkaline rocks of the Franspoort line, Pretoria district: *Geol. Soc. South Africa Trans.* **25**, 81–100, 1923.
- Petrographic nomenclature: *Geol. Mag.* **60**, 287–288, 1923.
- The problem of the alkaline rocks (Anniversary Address by the President): *Geol. Soc. South Africa Proc.* **25**, xix–xxxii, 1923.
- Useful aspects of geology; an introduction to geological science for engineers, mining men, prospectors, and all interested in the mineral industries. 197 p., illus., 1925; 2d ed. 183 p., illus., 1934, Thomas Murby and Co., London.
- The Bushveld igneous complex of the Transvaal (abstract): *Edinburgh Geol. Soc. Trans.* **11**, 401–402, 1925.
- Alkaline rocks and ring-intrusions of Pilansberg (Transvaal) (abstract): *Geol. Soc. London, Abs. Proc.* 1925–1926, no. **1145**, 42, 1926.
- Eruptive rocks; their genesis, composition, classification, and their relation to ore deposits, with a chapter on meteorites. 1st ed., 360 p., illus., Thomas Murby and Co., London (D. Van Nostrand Co., New York), 1927; 2d ed. 444 p., illus., 1943; 3d ed., 488 p., illus., 1949; 4th ed. 488 p., illus., 1951, Thomas Murby and Co., London (John Wiley and Sons, New York).

- On the relations between silica, alumina, and the bases in eruptive rocks, considered as a means of classification: *Geol. Mag.* **64**, 446–449, 1927; addendum, *Geol. Mag.* **65**, 192, 1928.
- The alkaline rocks of Franspoort, and Leeuwfontein: *15th Internat. Geol. Congress, South Africa 1929, Guidebook, Excursion B 10*, 8 p., 1929.
- Pilansberg, Part II of "The Rustenburg platinum deposits and Pilansberg" by P. A. Wagner and S. J. Shand: *15th Internat. Geol. Congress, South Africa 1929, Guidebook B 9*, 7–9, 1929.
- The classification of a glassy rock; the pitchstone of Wormit, Fifeshire: *Geol. Mag.* **66**, 116–121, 1929.
- The geology of Pilansberg (Pilaan's Berg) in the western Transvaal; a study of alkaline rocks and ring-intrusions: *Geol. Soc. South Africa Trans.* **31**, 97–156, 1929; supplementary remarks, *Proc.* **31**, liii, 1929.
- Instructions for using the quantitative mineralogical classification of eruptive rocks proposed by S. J. Shand. 16 p., tables, Thomas Murby and Co., London (D. Van Nostrand Co., New York), 1929.
- Limestone and the origin of feldspathoidal rocks; an aftermath of the Geological Congress: *Geol. Mag.* **67**, 415–427, 1930.
- The dolerite-chalk contact of Scawt Hill: *Geol. Mag.* **68**, 288, 1931.
- Phenocryst and inset: *Geol. Mag.* **68**, 480, 1931.
- The study of rocks. 224 p., illus., 1931; 2d ed., 236 p. illus., 1947; 3d ed. 236 p., illus., 1951, Thomas Murby and Co., London (D. Van Nostrand Co., New York).
- The genesis of leucite and melilite rocks: *Geol. Mag.* **69**, 561–562, 1932.
- The granite-syenite-limestone complex of Palabora, eastern Transvaal, and the associated apatite deposits: *Geol. Soc. South Africa Trans.* **34**, 81–105, 1932.
- The reaction between granitic magma and limestone at Palabora, Transvaal (abstract): *Geol. Soc. London, Abs. Proc.* 1931–1932, no. **1242**, 43–44, 1932.
- Discussion of "The genesis of the pyroxenite-apatite rocks of Palabora, eastern Transvaal" by A. L. du Toit: *Geol. Soc. South Africa Proc.* 1931, xlviii–xlix, 1932.
- Assimilation of limestone at Loch Borolan: *Geol. Mag.* **70**, 47–48, 1933.
- The lavas of Mauritius: *Geol. Soc. London, Quar. Jour.* **89**, 1–13, 1933; abstract, *Abs. Proc.* 1931–1932, no. **1282**, 44–45, 1932.
- Professor Holmes' hypothesis of the genesis of leucite and melilite rocks: *Geol. Mag.* **70**, 382–383, 1933.
- Zusammensetzung und Genesis der Alkaligesteine Südafrikas: *Min. Petr. Mitt.* **44**, 211–216, illus., 1933.
- Earth-lore; geology without jargon. 134 p., illus., 1933; 2d ed. 144 p., illus., 1937, Thomas Murby and Co., London (E. P. Dutton and Co., New York, 1938).
- The heavy minerals of kimberlite: *Geol. Soc. South Africa Trans.*, **37**, 57–68, 1935; discussion, *Proc.* **1934**, lxiv–lxvii, 1935.
- An olivine-trachyte from Mont Dore, Auvergne: *Geol. Mag.* **72**, 86–89, 1935.
- Eruptive rock names: *Geol. Mag.* **72**, 382–383, 1935.
- The mineralogical classification of igneous rocks; a comparison of recent proposals: *Jour. Geology* **43**, 609–617, 1935.
- Rift valley impressions: *Geol. Mag.* **73**, 307–312, 1936; abstract, *Geol. Soc. London, Abs. Proc.* no. **1313**, 96, 1936.
- The definition of augite-biotite-diorite: *Geol. Mag.* **73**, 479–480, 1936.
- The rocks of the Kedong scarp, Kenya rift valley: *Geol. Mag.* **74**, 262–271, 1937.
- Augite-biotite-diorite: *Geol. Mag.* **74**, 287, 1937.
- Note on some foyaites from near Liwonde, Nyasaland, in The Chilwa Series of southern

- Nyasaland, by F. Dixey, W. Campbell Smith, and C. B. Bisset: *Nyasaland Geol. Surv. Bull.* **5**, 53–54, 1937.
- Discussion of "South African melilite basalts and their relations" by M. S. Taljaard: *Geol. Soc. South Africa Proc.* **39**, 1936, xcvi, 1937.
- Discussion of "Phases of mineralisation in Namaqualand pegmatites" by T. W. Gevers: *Geol. Soc. South Africa Proc.* **40**, 1937, lvii, 1938.
- Review of "Our wandering continents; an hypothesis of continental drifting" by A. L. du Toit: *Jour. Geomorphology* **1**, 250–251, 1938.
- Loch Borolan laccolith, northwest Scotland: *Jour. Geology* **47**, 408–420, 1939.
- On the staining of feldspathoids, and on zonal structure in nepheline: *Am. Mineral.* **24**, 508–513, 1939.
- Memorial to Alfred Harker (1859–1939): *Geol. Soc. America Proc.* **1939**, 207–209, 1940.
- Discussion of "A poikilitic sodalite syenite from Pilansberg" by F. C. Partridge: *Geol. Soc. South Africa Proc.* **41**, 1938, lxx–lxxi, 1939.
- The malignite of Poohbah Lake, Ontario: *Geol. Mag.* **78**, 224–228, 1941.
- Memorial to Franz Julievitch Loewinson-Lessing: *Geol. Soc. America Proc.* **1940**, 227–228, 1941.
- Phase petrology in the Cortlandt complex, New York: *Geol. Soc. America Bull.* **53**, 409–428, 1942; abstract, **51**, 1944–1945, 1940.
- The Witsand meteorite, South-West Africa: *Am. Jour. Science* **240**, 67–71, 1942.
- Notes on cordierite: (A) cordierite crystals from a glass furnace; (B) cordierite from Horns Nek, Transvaal: *Am. Mineral.* **28**, 391–395, 1943.
- The species concept in petrology: *Am. Jour. Science* **242**, 45–52, 1944.
- The terminology of late-magmatic and post-magmatic processes: *Jour. Geology* **52**, 342–350, 1944.
- Memorial to Gustav Adolf Frederik Molengraaff: *Geol. Soc. America Proc.* **1943**, 205–207, 1944.
- Coronas and coronites: *Geol. Soc. America Bull.* **56**, 247–266, 1945.
- The present status of Daly's hypothesis of the alkaline rocks: *Am. Jour. Science* **243A** (Daly Volume), 495–507, 1945.
- Discussion; The origin of nepheline rocks in Ontario: *Jour. Geology* **54**, 398–401, 1946.
- Review of "Igneous minerals and rocks" by E. E. Wahlstrom: *Am. Mineral.* **32**, 697, 1947.
- History of a feldspar crystal. A contribution to the granite problem: *Geol. Soc. America Bull.* **60**, 1213–1214, 1949.
- Rocks of the mid-Atlantic ridge: *Jour. Geology* **57**, 89–92, 1949.
- Discussion of "Vermiculite at Loolekop, Palabora, North East Transvaal" by T. W. Gevers: *Geol. Soc. South Africa Trans.* **51**, 174–175, 1949.
- Rock-magma and rock-species: *Am. Mineral.* **35**, 922–930, 1950.
- Memorial to Sir John Flett: *Geol. Soc. America Proc.* **1949**, 163–164, 1950.
- Acceptance of the Lyell Medal of the Geological Society of London: *Geol. Soc. London, Abs. Proc.* 1949–1950, no. **1463**, 108–109, 1950.
- Mylonite, slickensides, and the Great Glen Fault: *Geol. Mag.* **88**, 423–428, 1951.
- Discussion of "The alkali complex at Spitskop, Sekukuniland, eastern Transvaal" by C. A. Strauss and F. C. Truter: *Geol. Soc. South Africa Trans.* **53**, 127, 1951.
- Discussion of "Post-Bushveld ultrabasic, alkali and carbonatitic eruptives at Magnet Heights, Sekukuniland, eastern Transvaal," by C. A. Strauss and F. C. Truter: *Geol. Soc. South Africa Trans.* **53**, 191, 1951.
- Rocks for chemists; an introduction to petrology for chemists and students of chemistry. 141 p., illus., Thomas Murby and Co., London (Pitman Pub. Corp., New York), 1952.
- The Great Glen crush belt: *Geol. Mag.* **90**, 70, 1953.
- Memorial of Frederick Eugene Wright: *Geol. Soc. London Proc.* 1954–1955, no. **1529**, 131–132, 1955.

MEMORIAL OF FRANTIŠEK SLAVÍK

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Not long ago we congratulated Professor František Slavík on his eightieth birthday and wished him good health for the next decade, and now the time has come for us to part with him. He died on January 27, 1957.

František Slavík, son of the historian František Augustin Slavík, was born on July 18, 1876 in Kutná Hora, a mining town in Middle Bohemia.

In 1895 he entered the philosophical faculty of the Charles University in Prague, where he studied natural history, chemistry and physics. From the very beginning of his studies he was distinguished by wide knowledge in several disciplines of natural sciences—zoology, botany, geology, mineralogy, chemistry and others. He was therefore highly respected by many of his school-mates. His "exceptional polymathy" and true fellowship was remembered by one of his oldest contemporaries, Professor Josef Kratochvíl, on the occasion of Slavík's eightieth birthday, who said: "He was not jealous of successes made by others, but was pleased by them. We all in the small club circle felt it and it sank deeply in our memory."

At the Charles University he was taught mineralogy by the prominent crystallographer Karel Vrba and petrology by Jindřich Barvíř. He studied chemistry with Karel Preis and Bohumil Brauner.

Professor Vrba recognized very early Slavík's abilities and made him his assistant in the second year of his studies. In 1889 Slavík became doctor of philosophy on the basis of a dissertation which had a principally petrological character: "On ore-bearing pyroxenic and biotitic gneiss at Pohled near Světlá n.S. *Journal of the Royal Bohemian Society of Sciences*, 1897, No. 34, Prague 1898.

In 1901–1902 he studied crystallography for one semester with Prof. P. Groth and petrology with Prof. E. Weinschenk in Munich. He remained Prof. Vrba's assistant up to 1903, when he was appointed as professor for grammar schools. He taught then in several classical and modern grammar schools of Prague. In 1905 he was admitted for a docent in mineralogy at the Charles University, where he was appointed in 1910 an assistant-professor and in 1916 professor in ordinary and director of the Mineralogical Institute of the Charles University. In the years 1907–1916 he worked simultaneously as a docent at the Technical High School of Prague. In 1937 he was elected rector of the Charles University in Prague.

The first forty years after he received the doctor's degree, Prof.



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1876–1957

Slavík devoted, practically undisturbed, to scientific work in a time of versatile international contacts, so necessary for the growth of a man of science. Slavík knew quite well several languages, especially English, French, German, Russian, Italian and Polish, which enabled him to take part actively at scientific conferences in various countries.

He was present at most international geological congresses of his time and at many other meetings of scientists abroad. With the exception of Albania and Portugal he probably knew all European countries. He had many friends all over the world and procured willingly for his collaborators and students comparative material from foreign countries.

Among his most distinguished students were Dr. Radim Nováček, docent in chemical mineralogy, known mainly for his studies on uranium minerals, and Dr. František Ulrich, professor of experimental mineralogy at the Charles University of Prague.

The Nazi occupation of Czechoslovakia in 1939–1945 interrupted the successful development of Slavík's school and dealt a heavy blow to Czechoslovakian mineralogy. It was not only that the Czech universities were closed. Professor Slavík loved freedom in all his life, and so he partook actively in the national resistance, with his collaborators F. Ulrich and R. Nováček,

On February 4, 1943, he and his wife, the mineralogist Dr. Ludmila Slavíková, were arrested by the Gestapo. He went through the prison of Pankrác and the concentration camps of Terezín, Auschwitz and Buchenwald. His wife was tortured to death in Rajsko near Auschwitz on February 18, 1943. František Ulrich and Radim Nováček were arrested by the Gestapo too. Ulrich was wounded when resisting the arrest and died. Nováček perished in the prison of Pankrác. Slavík's Mineralogical Institute was moved, the laboratory installations demolished and an "Institut für Rassenlehre" established in its former rooms.

After the liberation of Czechoslovakia, when Professor Slavík returned in June 1945 to his institute, it was empty. It will never be forgotten, how Professor Slavík, 69 years of age and back from the concentration camps, carried piles of books day after day, and worked more assiduously than those who helped him. Unforgettable were his self-sacrificing efforts to restore what had been destroyed by the Nazis, to replace those who had been murdered, and to secure the renewal and further development of Czechoslovakian mineralogy.

After an interval of six years Prof. Slavík started with his lectures and, although put on the retired list in 1947, he actively continued in lecturing at the Charles University practically until his death.

His distinguished services were recognized by many honors at home and abroad.

He was an ordinary member of the Czechoslovak Academy of Sciences, of the Royal Bohemian Society of Sciences and of many other scientific institutions in Czechoslovakia. In 1946 the Charles University of Prague conferred on him an honorary degree in natural sciences.

Abroad he was elected a corresponding member of the Mineralogical Society of America, an honorary member of the Mineralogical Society in London, the Geological Society of Great Britain, Société française de Minéralogie et de Cristallographie, the All-Union Mineralogical Society of the USSR, Société géologique de Belgique, and a member of the Rumanian Academy of Sciences.

From 1920 up till his death he abstracted regularly the Czechoslovak scientific papers for the *Mineralogical Abstracts* as a co-worker of Dr. L. J. Spencer.

Czechoslovakian mineralogy has lost in Professor Slavík its most

distinguished member. He was respected not only for his scientific activity, but also for his unusual modesty and kindness. He was always prepared to comply with the wishes of anyone who came with good will. He always spared time even for beginning students and private collectors of minerals. He used to give unselfishly all publications, which he had received during his long and rich interchange with foreign countries, to the library of the Mineralogical Institute. Thanks to him the library of separata of the Mineralogical Institute of the Charles University no doubt is one of the largest in Central Europe.

SELECTED BIBLIOGRAPHY OF FRANTIŠEK SLAVÍK

A complete list of Professor Slavík's publications was compiled by Prof. J. Novák in the volume commemorating the eightieth birthday of Prof. Slavík: *Sborník k osmdesátinám akademika Františka Slavíka*, pp. 5–42, Prague, 1957.

1. Über Triplite von Wien und Cyrrillhof in Mähren und seine Zersetzungsprodukte. (With F. Kovář). *Verhandl. der k.k.geolog.Reichsanstalt*, **1900**, 387–404.
2. Über die rothen Zoisite aus Mähren. *Centralblatt für Min., Geol., Paleont.*, **1901**, 686–690.
3. Über die wahrscheinliche Identität von Lussatit und Tridymit. *Centralblatt für Min., Geol., Paleont.*, **1901**, 690–692.
4. Beiträge zur Kenntnis der Ammoniumhalogenverbindungen. *Zeits. für Kryst.*, **36**, 268–276, 1902.
5. Datolith unterhalb Lištic bei Beroun. (With J. Fišer). *Centralblatt für Min., Geol., Paleont.*, **1903**, 229–235.
6. Zur Frage der Kohle im Diabas von Radotín. *Verhandl. der k.k.geolog. Reichsanstalt*, **1902**, 194–196.
7. Mineralogische Notizen: 1. Zur Kenntnis der Mineralien von Schlaggenwald; 2. Titanit von Skaatö bei Kragerö; 3. Krokoitkrystall von Dundas; 4. Chrysoberyll von Marschendorf in Mähren. *Zeits. Krist.*, **39**, 294–305, 1904.
8. Über die Alaun- und Pyritschiefer Westböhmens. *Bull. internat. Acad. tchéque des Sciences*, **9**, 47–112, 1904.
9. Über einen Granathornfels von Predazzo. *Centralblatt für Min., Geol., Paleont.*, **1904**, 661–666.
10. Zur Mineralogie von Mähren. *Centralblatt für Min., Geol., Paleont.*, **1904**, 353–363.
11. Studien über den Mieser Erzdistrikt und einige von seinen Mineralien. *Bull. internat. Acad. tchéque des Sciences*, **10**, 97–124, Prague 1905.
12. Über Salmiakkrystalle von Vesuv a.d.J.1906. *Bull. internat. Acad. tchéque des Sciences*, **12**, 50–54, Prague 1908.
13. Spilitische Ergussgesteine im Präkambrium zwischen Kladno und Klatau. *Archiv für die naturwissenschaftliche Landesdurchforschung von Böhmen*, **14**, No. 2, 1–176, Prague 1908.
14. Phenakit von Brasilien. *Bull. internat. Acad. tchéque des Sciences*, **14**, 90–97, Prague 1909. See also: *Centralblatt für Min. Geol., Paleont.*, **1909**, 264–267.
15. Über die Manganmineralien von der Veitsch in Steiermark. (With A. Hofmann.) *Bull. internat. Acad. tchéque des Sciences*, **14**, Prague 1909.
16. Über einige Baryte der Kladnoer Steinkohlenformation. *Bull. internat. Acad. tchéque des Sciences*, **14**, 248–253, 1909.
17. Whewellit von Schlan. *Bull. internat. Acad. tchéque des Sciences*, **13**, 154–162, 1909.

18. Zweite Mitteilung über den Schlaner Whewellit. *Bull. internat. Acad. tchéque des Sciences*, **14**, 367–376, 1909.
19. Über "Dürrerze" von Příbram. (With A. Hofmann). *Bull. internat. Acad. tchéque des Sciences*, **15**, 65–106, 1910.
20. Über Telluride in einem Aplitgang bei Zduchovic. *Sitzungsberichte d. kön. böhm. Gesellschaft der Wiss.*, II. Classe, **1909**, No. XI, 1–11, Prague.
21. Morphologie des Samsonits. *Bull. internat. Acad. tchéque des Sciences*, **16**, 57–66, 1911.
22. Über das goldführende Gebiet von Kasejovic. (With A. Hofmann.) *Bull. internat. Acad. tchéque des Sciences*, **17**, 249–277, Prague 1912.—2nd part: *ibid.*, **18**, pp. 94–140, 1913.
23. Zur Kenntnis des Goldvorkommens von Roudný. *Sitzungsberichte der kön. böhm. Gesellschaft der Wissenschaften*, II. Classe, **1912**, No. 12, 1–28, Prague.
24. Achsenverhältniss des Jamesonit? *Centralblatt für Min., Geol., Paleont.*, **1914**, pp. 7–12.
25. Die goldquarzgänge Mittelböhmens. *Zeitschr. für praktische Geologie*, **22**, 343–352 and 353–373, 1914.
26. Neue Phosphate von Greifenstein bei Ehrenfriedensdorf. *Bull. internat. Acad. tchéque des Sciences*, **19**, 108–123, Prague, 1914.
27. Sur les fluorophosphates ternaires de Al_2O_3 , RO et R_2O (morinite, ježekite, lacroixite). *Bull. de la Soc. française de Minéralogie*, **37**, 152–162, 1914.
28. Notiz über den Lacroixit. *Bull. internat. Acad. tchéque des Sciences*, **20**, 372–373, Prague 1916 (Presented 1915).
29. Études sur les minerais de fer du silurien inférieur de la Bohême. (With L. Slavíková). *Bull. internat. Acad. tchéque des Sciences*, **22**, 1–24, Prague 1920 (Presented 1917). This paper presents a summary of a tripartite study published in Czech language under the title: "Studie o železných rudách českého spodního siluru," *Rozpravy České Akademie věd*, **26** (1917), No. 33, No. 37, No. 62, Prague 1918.
30. Der Phosphorgehalt der Eisenerze im böhmischen Untersilur. *Bergbau und Hütte*, **4**, Heft 5, 1–9, 1918.
31. Die Chistolitschiefer in der Umgebung von Rožmitál. *Bull. internat. Acad. tchéque des Sciences*, **21** (1917), pp. 105–112, Prague 1919. (Presented 1915).
32. Über Spillite im Příbramer Algonkium. *Bull. internat. Acad. tchéque des Sciences*, **21** (1917), 137–152, Prague 1919 (Presented 1915).
33. Über Tellurwismut aus den böhmischen Goldgängen. *Bull. internat. Acad. tchéque des Sciences*, **22** (1920), 100–102, Prague 1920.
34. Deux roches éruptives anchimonominérales dans le gabbro de la Bohême occidentale. *Bull. internat. Acad. tchéque des Sciences*, **23** (1923), 190–192, Prague 1923 (Presented 1922).
35. Minerais de fer pisolitiques bauxitifères dans la crétacé de la Bohême. *Bull. internat. Acad. tchéque des Sciences*, **23** (1923), 172–173, Prague 1923. (Presented 1922).
36. Chapters on tellurium and tellurides in the "Handbuch der Mineralchemie" Doelter, IV, part I, 845–887, 1926.
37. Note on zaraitite from Bohemia, Pennsylvania and Tasmania. *Am. Mineral.*, **11**, 279–280, 1926.
38. Anthophyllite-asbest manganésifère de Chvaletice en Bohême. (With V. Veselý.) *Bull. internat. Acad. tchéque des Sciences*, **28** (1927), 64–70, Prague 1927.
39. The Minerals of Příbram. *Am. Mineral.*, **12**, 345–350, 1927.
40. Nerosty z ložisk manganových rud v Železných horách. *Časopis Národního musea, odd. přír.*, **102**, 113–127, Prague 1928.
41. Note sur l'anthophyllite-asbeste manganésifère des mines de Jacobeni-Arșița. *Bull. de l'Univ. Iași*, **1928**, 133–135.

42. Les "Pillow-lavas" algonkiennes de la Boheme. *Comptes rendus de la XIV^e Session en Espagne, Congres géologique international 1926*, Fasc. IV, 1389-1395, Madrid 1928.
43. Place names of mineral-localities in central Europe. (With L. J. Spencer.) *Min. Magazine*, **21**, 441-479, 1928.
44. Gisements de manganèse en Bohême orientale. *Congrès Internat. des Mines etc., VI^e Session (1930), Compte rendu de la session de géologie appliquée*, 141-145, Liège 1931.
45. The copper deposits of Czechoslovakia. Copper Resources of the World, XVI. Internat. Geol. Congress. 555-556, Washington 1933.
46. Iz geochimii manganca i fosfora. *Vernadský volume*, 245-250, Moscow 1936.
47. L'activité volcanique dans le Barrandien. *Bull. de la Soc. géologique de France*, **7** (1937), 527-540.
48. Hatchettin z ložiska rumělky u Merníku. *Sborník Muzea Dionýza Stára*, **1**, 101-104, Banská Štiavnica (Czechoslovakia), 1937. (With an English summary).
49. Nerostopis a ložiska užitečných minerálů Slovenska. (In Czech), *Carpatica III*, No. 2 (pp. 62), Prague 1939. 2nd edition in Slovakian language, published by Matice slovenská in Martin in 1951.
50. Notes on jaspers and similar quartz substances of NE Bohemia. *Věstník Král. české spol. nauk, tř. mat.-přir.*, **1945**, 1-4, Prague 1946.
51. "Skarn" and its resorption by pegmatite at Lišná near Nové Město n.M. (Czech with English summary.) *Sborník geolog. ústavu*, **18**, 573-579, Prague 1951.
52. Mineralogie (with J. Novák and O. Pacák). (Textbook in Czech), pp. 415, fig. 329. 4th edition, Prague 1956.

MEMORIAL OF BENNO WASSERSTEIN*

MICHAEL FLEISCHER, *U. S. Geological Survey, Washington, D. C.*

Benno Wasserstein's many friends were shocked to learn of his death on December 12, 1956, when a chartered plane crashed during takeoff from the airport at San Salvador, El Salvador. Two other employees of the Kaiser Aluminum and Chemical company and the pilot were also killed in the accident. Wasserstein had left his native South Africa only a month previous to establish and supervise a minerals research laboratory on the west coast for the Kaiser Co.; he had approached his new position with characteristic enthusiasm and impatience to get things moving.

Benno Wasserstein was born on July 23, 1906, at Wynberg, Cape Province, Union of South Africa. His parents were of Austrian descent. He attended the South African College School in Cape Town, then from 1926 to 1929 the University of Cape Town, where he received the degrees of B.S. and M.S. in Geology and Mineralogy. From 1930 to 1932, he studied at the University of Munich, Germany, from which he received the Ph.D. degree (*magna cum laude*). His thesis dealt with the petrogenesis of the sandstone between Nürnberg and Weissenburg.

On his return to Africa, he was employed by the British South Africa Co. as a field geologist in Northern Rhodesia and Bechuanaland Protectorate, then joined the Mines Department of the Union of South Africa in 1934 as assistant geologist. Wasserstein remained with the Department of Mines until 1956. His work dealt with field investigations of mineral deposits until 1939, when he was placed in charge of laboratory work in mineralogy, succeeding F. C. Partridge. He told me some years later that although he was well trained in mineralogy, he accepted the transfer with considerable apprehension when he learned that he was expected to use the new spectrograph, which he had never seen! As anyone who knew him could have predicted, Wasserstein not only became an accomplished spectrographer, but an enthusiast on the possibilities of applying spectrographic analysis to the solution of geological problems.

In 1945 Wasserstein came to the United States to spend a year at the Massachusetts Institute of Technology for advanced training in spectrographic analysis and also in x-ray methods. He and Mrs. Wasserstein, who joined him for part of the year, made many friends among American mineralogists. On his return, he introduced x-ray methods and differential thermal analysis in his laboratory, which he headed until 1955, when he became Principal Geologist in charge of the Economic Branch. In July 1956, he attended, by special invitation, the Gordon Research Con-

* Publication authorized by the Director, U. S. Geological Survey.



BENNO WASSERSTEIN
1906-1956

ference in New Hampshire to discuss his suggestion that the size of the unit cell of uraninite could be used as a measure of geological age. The invitation to join the Kaiser company followed. The decision to leave South Africa was a difficult one to make, but the challenge of the new position was too great for him to set aside.

Wasserstein brought to his laboratory work the viewpoint of the field geologist; he was equally impatient with the laboratory worker who, ignoring field relations, treated samples as though they had grown in a vacuum, and with the field geologist who did not avail himself of the help offered by the laboratory. His enthusiasm was infectious; I like to re-read our correspondence of fourteen years for the stimulation of the many ideas he had and so freely passed on to others.

The attached bibliography represents only a small part of his contribution to science. A number of the younger mineralogists of South Africa were trained in his laboratory and have already made notable contributions of their own.

Wasserstein was elected a Fellow of the Mineralogical Society of America in 1949. He was also a member of Sigma Xi and of the Geological Society of South Africa. He served for several years as Observer, Commission on Geochemistry, International Union of Pure and Applied Chemistry.

Wasserstein is survived by his father, his son Louis, age 12, and his wife, Doreen, who supplied much information for this memorial.

BIBLIOGRAPHY OF BENNO WASSERSTEIN

- Gypsum in the Union of South Africa. *Geol. Survey South Africa, Geol. Ser., Bull. No. 3*, 35 pp. (1935).
- Some notes on the critical zone of the Bushveld gabbro at the Swartkop chrome mine in the Rustenburg District. *Geol. Soc. South Africa, Trans.*, **39**, 215–222 (1936).
- The chromite deposits of the Bushveld igneous complex. *Geol. Survey South Africa, Geol. Ser., Bull. No. 10* (1936).
- Note on nickeliferous pyrite from the Leeuwpoot tin mine. *Geol. Soc. South Africa, Trans.*, **44**, 35–37 (1941).
- On the presence of boron in braunite and manganese ores. *Econ. Geology*, **38**, 389–398 (1943).
- Observations on two precision lattice measurements of pyrite from Leadville, Colorado. *Am. Mineral.*, **34**, 731–735 (1949).
- A new approach to the relative age determinations of uraninites and thorianites. *Geol. Soc. South Africa, Proc.*, xlv–xlv (1950).
- South African granites and their boron content. *Geochim. et Cosmochim. Acta*, **1**, 329–338 (1951).
- Precision lattice measurements of galena. *Am. Miner.*, **36**, 102–115 (1951).
- Cube-edges of uraninites as a criterion of age. *Nature*, **168**, 380 (1951).
- Ages of uraninites by a new method. *Nature*, **174**, 1004–1005 (1954).
- Age of uraninites from crystallographic data. Reply to Hoekstra and Katz. *Nature*, **175**, 605–606 (1955).
- Ages of pitchblendes by x-ray diffraction. *Nature*, **176**, 159–160 (1955).

PRESENTATION OF THE ROEBLING MEDAL TO WALTER F. HUNT

LEWIS S. RAMSDELL, *University of Michigan, Ann Arbor, Michigan.*

Mr. President, Fellows and Members of the Mineralogical Society of America, and Guests:

Our Society has already awarded the Roebling Medal for meritorious service in Mineralogy on fifteen occasions. On the occasion of this, the sixteenth award, we are honoring a man who has rendered not only meritorious service, but a unique service to our science.

It is a great personal pleasure to me to have the honor of making this presentation, for my entire professional life has been very closely related to Dr. Hunt. Since my first course with him in my senior year at the University of Michigan some 40 years ago, there has been an almost continuous association with him.

Walter F. Hunt graduated in chemistry at the University of Michigan in 1904. As a graduate student he became interested in mineralogy, and served as an assistant in the department. The degree of Doctor of Philosophy was conferred upon him in 1915, the subject of his dissertation being the origin of the sulfur deposits of Sicily. At that time he had reached the rank of assistant professor. In 1922 he was made Professor of Petrology and in 1933 he was appointed Chairman of the Department of Mineralogy at the University. He held this position until he became Professor Emeritus in 1952. As a graduate student, and as a permanent member of the Department, he was interested in research as well as teaching. He published various papers and was an abstractor for *Chemical Abstracts*.

In 1922 Professor Hunt had before him the prospect of continuing the happy combination of teaching, writing and research, which is possible in a university. But when the newly organized Mineralogical Society of America took over *The American Mineralogist* as its official Journal, and asked him to become its editor, he accepted. It may be that it never occurred to him that the editorship might be the time-consuming task that it has become, or that he might serve as editor for thirty-five years. At any rate, he accepted the task, and over this long period has rendered distinguished service, not only to mineralogy in the United States but over the entire world.

With the continuing development of our science, and the growth of both our Society and the Journal, he had to devote more and more time to the editorial duties. Although he continued his teaching, and found time to be the co-author of two books, the opportunities for research activity were practically eliminated.

During most of this period of 40 years, we have had our offices across the hall from each other. I will not strain your credulity by saying that in this period there has never been disagreement, or that I have never heard editorial grumblings about authors who send in poorly prepared manuscripts, who use three words where one would do, or who want to rewrite their papers after they have received galley proof. But I do want to say that he seldom lost his temper and that he has been patient, considerate, and helpful. He never developed the cantankerous nature supposedly characteristic of editors. I have never heard him express any regrets at being editor for this long period, and I think that on the whole he has had a pretty good time doing it. He certainly looks as if life had been rather good to him.

During his editorship the Journal has achieved a leading world position, in size, in number of subscribers, and in influence. It has had a significant part in the rapid growth of mineralogy and related sciences.

Dr. Hunt has never sought office, but he has never shirked responsibility. His ability as a teacher, his friendliness and interest in others have won him a host of friends. After my long and close association with him, I am happy to have the privilege that is mine today.

Mr. President, it is an honor to present Walter Frederick Hunt as the sixteenth recipient of the Washington A. Roebling Medal of the Mineralogical Society of America, for his long and distinguished service as Editor of *The American Mineralogist*.

ACCEPTANCE OF THE ROEBLING MEDAL OF THE MINERALOGICAL SOCIETY OF AMERICA

WALTER F. HUNT, *University of Michigan, Ann Arbor, Michigan.*

Mr. President, Professor Ramsdell, Fellows, Members and Guests of the Mineralogical Society of America:

The letter from your President bearing the news that the Council had selected your former editor as the recipient of the Roebling Medal came as a distinct and startling surprise. Such a special honor can be accepted only with an expression of sincere appreciation and deep humility. When one surveys the list of past recipients and their accomplishments and the possibilities among those present worthy of this distinction, the thought comes to mind that in this particular instance the Council has given a very liberal interpretation to the term "meritorious." Nevertheless, I am indeed deeply grateful for this generous recognition of services rendered during the extended period I have been privileged to serve you.

At the beginning of every worthy undertaking fond hopes are expressed and tentative goals assigned by the founders of an organization for possible future attainment, and at irregular intervals an inventory is taken to review accomplishments and note what progress, if any, has been made towards those desired ends. I believe this is an opportune time to reflect on some of the major events that have marked the progress of our Society as revealed by the Journal during the past four decades. I am well aware that on previous occasions Dean Kraus in his presidential address in 1920 spoke on the events that led to the founding of the Society, and at the annual meeting in 1929 spoke on the progress made by the Society during its first decade. With your kind permission I should like to add certain additional observations and comments and thus bring the very interesting narrative up to date.

Our older members may recall that the Journal, *The American Mineralogist*, antedates the founding of the Mineralogical Society of America by $3\frac{1}{2}$ years. The first issue appeared in July 1916 under the editorship of Wallace Goold Levison, with Edgar T. Wherry as one of the associate editors. Wherry succeeded Levison as editor during the three-year period 1919 through 1921.

The project of publishing the magazine originated with the Philadelphia Mineralogical Society. Other mineralogical organizations were invited, and the New York Mineralogical Club and Mineral Collectors Association designated their secretaries to serve as associate editors of a journal devoted "to promote mineralogy as a hobby as well as a science." It was established as a medium of exchange of notices of proceedings of



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the various local mineralogical societies, and as an outlet for popular and semi-technical papers on mineral localities and new occurrences, as the subscribers were to a large extent mineral collectors, museum curators and laymen with a love of minerals as an avocation. However, it was the hope of the founders to enlist the assistance of serious students of mineralogy and quite a few short, technical papers were contributed by professional mineralogists.

In passing it should be emphasized that due credit should be given those early pioneers of the *Journal* who with very little capital but undaunted courage saw a pressing need and met it.

An unusually impressive issue during this early period was the June 1918 number commemorating the 175th anniversary of the birth of Abbé Haüy. In that issue eight papers by eminent mineralogists record the life, scientific contributions and influence of this distinguished crystallographer.

The records show that the first suggestion of organizing a separate society of mineralogists and petrographers was made by A. N. Winchell in January 1913 in a letter sent to those especially interested in mineralogy and petrography, but the replies were of such a varied character that a postponement was decided upon. But the desirability and need of a separate organization grew rapidly and the question came up again at the meetings of the Geological Society of America at Albany in December 1916, and a small group of six decided to launch an active campaign looking toward the formation of a Mineralogical Society of America. The entrance of the United States in the World War caused another delay, and it was not until the winter meeting of the GSA in 1919 that the organization meeting was held in the Mineralogical Museum of Harvard University on December 30. At that meeting the decision was also reached for the newly formed Society to take over and enlarge the small journal which was having financial difficulties, so that beginning with the January 1920 issue *The American Mineralogist* became the official publication of The Mineralogical Society of America.

It became obvious that with this new affiliation the policy of the *Journal* would require drastic changes. As it was now the official publication of a national scientific organization, the standing of the Society both here and abroad would be judged largely by the type of articles that were accepted. In other words, the editorial sights had to be raised if our *Journal* was to be considered on the same plane with similar European periodicals.

It can be truthfully stated that during this transitional period the task of maintaining an equitable balance between semipopular and technical contributions was an extremely difficult one, and the editor was fre-

quently caught in the cross-fire of criticism from partisans of both sides. Perhaps I can clarify this by quoting a sentence from a letter I received in January 1930: "I would just as soon that you stop mailing the same, I am just as well off without it, as with it." But this acid criticism was completely neutralized by another letter received somewhat later from one of the original fellows of the Society, and again I quote: "*The American Mineralogist* continues to improve from year to year for which all of us can thank you." And so the struggle continued for a period of years, but the ultimate goal was always kept in sight.

The growth of the Journal during this early period was extremely slow, as the mounting costs of publication soon equaled the increase in dues from a slightly increased membership. It was not until the Society received from Col. Washington A. Roebling a handsome endowment that the Journal took on a new lease of life and advanced to a new and higher plateau of endeavor.

Perhaps some of you have forgotten what appeared at the time as a passing remark in a letter that initiated this generous gift. The incident is recorded by Palache in his acceptance speech of the Roebling Medal. The letter to Col. Roebling called attention to the publication in 1925 of two special numbers, one by Michigan and one by Harvard, which were largely financed by the institutions furnishing the material. Palache asked the Colonel what he thought of this arrangement and expressed the hope that the time would come when *The American Mineralogist* would be sufficiently endowed to be able to publish papers without the author or his institution having to bear the charges and concluded (and I quote): "I would invite your earnest consideration of this suggestion for a movement to secure a permanent fund which would be ultimately not less than \$50,000." Colonel Roebling did not reply to this letter but within a few days he transferred to the treasurer of the Society 45 one-thousand-dollar municipal bonds bearing 5% interest, with the suggestion that the whole or part of it be devoted to the publication of the Journal, which in his words "has been conducted on too narrow a margin." This magazine, he continued, "is the life of the Society. Its perusal is a pleasure to all lovers of minerals." The effect of that liberal gift was reflected in subsequent enlarged issues and more liberal allowances for illustrations.

The first suggestion of the desirability of establishing medals or awards to recognize unusual achievements and stimulate interest in mineralogy was made by E. H. Kraus in December 1929 at the Washington meeting, in his address in which the activities of the first ten years of the Society were reviewed. This suggestion led to the appointment of a special committee at the Toronto meeting in 1930 and the establishment of the

Roebling Medal, which was presented for the first time to Charles Palache in 1937, and awarded annually since then, with five exceptions—1939, 1942, 1943, 1944, and 1951.

More recently, in November 1949, the Council authorized the granting of the Mineralogical Society of America Award to recognize an outstanding contribution or series of contributions published by the recipient at the age of 35 years or less. This recognition became operative in 1951.

The passing years again brought marked increases in publication costs, and once more the Society was in need of additional financial assistance in order to maintain the pace and meet the increasing demands of a growing periodical. To meet this situation two methods were employed with marked success. From time to time large special numbers were issued, the excess cost of which was borne by the institution or organization submitting the manuscripts, or in part by friends and associates of those to whom these special issues were dedicated. Thus, the staff of the Geochemistry and Petrology Branch of the U. S. Geological Survey assumed responsibility for one special issue, aggregating 36 articles; the University of Michigan for three issues, totaling 41 articles; and Harvard University for eight issues, comprising 130 articles.¹ These bargain issues for the members of the Society did not entail additional strains on our treasury. Also, a grant of \$1100 was obtained from the National Science Foundation to aid in printing one of the special issues—the Ross-Schaller number.

The second source of additional income to meet publication costs came from the parent organization, the Geological Society of America, through grants by their Council from the Penrose Fund. This began with an initial grant of \$1500 in 1934 and continued annually on this level through 1941. Then as the need became more pressing the grant was very generously increased almost annually, and if my totals are correct, and I believe they are, we have received during the 23 intervening years slightly over \$86,000. Truly a very generous and discerning parent, and for this timely assistance our Society is extremely grateful and expresses its deep appreciation.

At this point the question may well be raised as to the tangible returns, to the science in general and to the members of the Society in particular, that these expenditures have produced. The Council in the early twenties appointed a Committee on Nomenclature and Classification of Minerals in an attempt to establish uniformity in spelling of mineral names and to clarify a number of other matters of general in-

¹ Another Harvard issue is now in press and will appear this year as the November-December number.

terest, such as the use of standard abbreviations for optical properties and proper adjectival endings of chemical elements used for modifiers to mineral names. The Committee, with a personnel that has varied over the years, is still at work and has reported some gratifying results.

In the beginning it was the hope that possibly some international agreement might be reached with several leading European mineralogical societies, but it soon became apparent that this was impossible. However, through numerous exchanges with a similar British committee and with the cooperation of the authors of the new Dana edition it is gratifying to note that a number of worth-while agreements were reached which have produced greater uniformity among the English-speaking countries than had previously existed.

In the early days of the Society while our membership still included a large number of mineral collectors and laymen, a rather persistent demand came to the editor's desk for a publication of a complete Directory of American and Canadian Mineral Collections. This prodigious task was entrusted to Samuel G. Gordon of the Academy of Natural Sciences of Philadelphia, at that time one of our associate editors. Through questionnaires mailed to institutions and numerous personal letters, he accumulated data for about 700 public and private collections, representing the most recent and authoritative information obtainable, listing alphabetically by states the location, the approximate number of specimens, and when the collections were open for general inspection. This fund of information was made available to our readers in five successive installments, which were then rebound in a single reprint for more convenient distribution.

World War II presented a number of pressing needs. One of these related to the efficient use of the diamond in industry. This situation was rendered especially acute through an interruption of the supply of wire-drawing dies formerly produced in the low countries and France. As the cutting power of the diamond is based upon an intimate knowledge of its crystallographic and structural properties, the crystallographers were invited to co-operate with industry in an attempt to solve some of the difficulties and accelerate production. With Dean Kraus as organizer and chairman, three symposia on the diamond were held and the 24 papers, prepared by specialists conversant with the varied uses of the diamond, were published in 1942, 1943, and 1946. The reaction to this series of papers was very gratifying as reflected in the unusual demand for reprints both here and abroad.

About the same time (1945) another very conspicuous issue made its appearance in the form of the 264-page *Symposium on Quartz Oscillator Plates*. These extremely valuable and timely contributions on the geology

of quartz crystal deposits and on the inspection, grading, cutting and testing of thin quartz wafers were made possible largely through the efforts of Drs. Frondel, Parrish, Gordon and their associates. Likewise substantial financial assistance was received from the Reeves Sound Laboratories and North American Philips Company to help defray the heavy expenses involved in the printing of this very large and highly illustrative number. The issue contains 14 authoritative articles and the demand for copies from individual organizations not on our regular mailing list has been so great that it has been reprinted three times.

At the November 1948 meeting of the Council, the late Professor Peacock (then President) reported that the University of Toronto had decided to terminate the *University of Toronto Studies* and that no practical way had been found to continue the publication of *Contributions to Canadian Mineralogy*. In order to preserve the continuity of the Canadian journal, our Council agreed to devote annually a regular issue of *The American Mineralogist* to a collection of papers by Canadian mineralogists. This policy was continued for seven years, first under the editorship of M. A. Peacock and more recently with L. G. Berry in charge. During this period, 1949-1955, *The American Mineralogist* had the opportunity to assist our Canadian colleagues through the publication of 112 articles, aggregating about 1000 pages.

As you no doubt have been informed, ways and means have been found, through the organization of the Mineralogical Association of Canada, to re-establish their journal, known now as *The Canadian Mineralogist*. We wish them success in this undertaking, as there appears to be sufficient available material to justify expanding outlets for mineralogical papers.

In conclusion, in summarizing the achievements of the Journal from the time it became the official publication of the Society through 1956, may I quote a few figures, realizing that quantity is not always a true measure of scholarly performance. However, it is still necessary at times to employ tangible measurable units and speak in terms of the number of printed pages. It may be of some interest to note that in your Journal 25,633 pages of mineralogical literature have been printed, including 2191 main or major articles received from authors at home and abroad. This figure includes complete accounts of 184 new minerals described in detail for the first time. In some years 25 to 30 manuscripts were received from contributors residing beyond our own borders, testifying to the influence of the Journal in distant lands.

An inspection of the scope of subject matter treated reveals an amazing range of topics, from the composition and structure of meteorites that have come to us from outer space, to the mineral-chemical composi-

tion and alteration products of the components comprising the crust of the earth, and even extends, to quote a title of a paper published in March 1943, to "Some petrological concepts and the interior of the earth."

The Society owes an expression of sincere thanks for the valiant service performed by Dr. Fleischer, who since 1941 has had charge of the section "New Mineral Names." His critical remarks and sound judgment in evaluating the propriety of proposed new mineral names have been of immeasurable assistance to our profession. As an indication of the value of this service, at the close of the first ten years of his tenure his report shows that of 164 new names proposed, only 77 appeared to be valid, the others were shown to be identical with previously known minerals, or unnecessary names for varieties, or based on insufficient data. In short, there were more mineral names discredited than valid species established.

This, then, is a brief summary of some of the accomplishments thus far. I am quite certain many of you will recall other important events that could have been included, but time will not permit further extensions. I hope, however, that in the topics selected I have stressed the fact that considerable progress has been achieved; the Journal has grown in prestige and stature, and this progress has been brought about through excellent team-work and the loyal cooperation and support given the editor and his associates by the officers and the various committees of the Society. If the past is any indication of what the future has in store, we may look forward with confidence to even greater achievements in the years to come.

PRESENTATION OF THE MINERALOGICAL SOCIETY OF AMERICA AWARD TO RUSTUM ROY

E. F. OSBORN, *College of Mineral Industries, The Pennsylvania State University, University Park, Pennsylvania.*

Mr. President, Fellows, and Members of the Mineralogical Society of America, and Guests:

The Mineralogical Society of America Award was established to honor a young scientist who has made a notable contribution in the broad field of mineralogy. I can think of no one more deserving of this award than this year's recipient, Dr. Rustum Roy.

Rarely can it be said that security regulations have benefited American science, yet we have an example here. Rustum came to this country in 1945 on a mission for the Government of India. He had a Master's degree in chemistry and a year and a half's experience in research for the Council of Scientific and Industrial Research of the Government of India. His mission was to study American methods of processing and utilizing mica. Various government and company security regulations in force at that time, however, prevented his gaining access to many operations and laboratories which he wanted to visit. Hence, he could not complete his job. Faced with this discouraging situation, he prevailed on his Government to permit him to remain in this country, but with his mission changed to that of a candidate for a Ph.D. degree. Thus did he happen to come to Penn State in 1946—the same year that I joined the faculty of that institution. He became the first of the students doing research with me to receive a Ph.D. degree. The second happened to be a comely, modest and very able geochemist from the University of Oregon, by the name of Della Martin. A few days after receiving her degree, she became Dr. Della Martin Roy. Rustum and Della have collaborated on many pieces of research. They also find time to raise three sons.

Rustum's first published researches were on phase equilibria in the system lithia-alumina-silica. This led to a more detailed study of the lithia aluminosilicates. In collaboration with Della, he synthesized for the first time the low temperature structures corresponding to the minerals eucryptite, spodumene and petalite, and presented a picture of the compositional and stability relationships existing among these interesting aluminosilicates.

Hydrothermal techniques used in these studies were improved upon and applied to many other mineralogical and geochemical problems. Extensive studies were made, for example, of the alumina-silica-water system, of the magnesia-alumina-silica-water system, and of the lime-

alumina-water system. Interesting and fundamental structural relationships among phases have been studied at length, as for example on "Multiple Ion Substitution in the Perovskite Lattice," or in collaboration with Dr. Keith on "Structural Relations Among Double Oxides of Trivalent Elements," or again in a series of papers now appearing on "Studies of Silica Structure Phases." In the past eight years sixty publications have appeared with Rustum as author or coauthor.

This is amazing productivity, and his type of research I believe is becoming of increasing importance in the earth sciences. As Professor of Geochemistry he is able to pass on to graduate students his knowledge, his manner of approach to problems, and his contagious enthusiasm for research.

Although Rustum hardly needs a stimulant, nevertheless I am sure that this award will serve as such to him. On behalf of the members of the Mineralogical Society of America, Mr. President, I have the privilege to present to you Dr. Rustum Roy for the Seventh Mineralogical Society of America Award.

ACCEPTANCE OF THE 1957 MSA AWARD

RUSTUM ROY, *College of Mineral Industries,
The Pennsylvania State University.*

Mr. President, Dean Osborn, Fellows, Members and Guests of the Society:

Let me first express my sincere thanks—inadequate as they must appear—to the Society for honouring me in this way. I view especially with admiration the wisdom and the vision of the Selection Committee members who have seen fit not to limit the award to U. S. Nationals, nor even to “Mineralogists” in a technical sense. Two of the award winners hold no formal degrees in the earth sciences, and three are not nationals.

If I repeat what nearly all my predecessors have said—that, in reality, the Award is given to the community of scientists and administrators which the individual represents—it is simply because it is felt so keenly by any person in the position in which I am today. Perhaps it is even more obviously true in my case as an alien who has been so wholly accepted by the community at large and by my colleagues in particular. In my case this community has been the Mineral Industries College at Penn State which has provided the nurturing circumstances, financial support and above all personal encouragement. It was Dr. P. D. Krynine and the late Dr. W. M. Myers who by this personal interest got me started in the Earth Sciences. My debt to Dean Osborn on all counts as teacher, research supervisor and administrator is obvious to all—likewise to his successor, Frank Tuttle. A glance at my bibliography—almost all joint papers—will tell you only a part of what I owe my students and colleagues. This working together, arguing and learning from co-workers, such as my wife and Bob DeVries, is what I treasure most out of my research experience.

I do not want to dwell on technical matters today: let me just tell you of the distant goal of our work. We are at Penn State an experimental group, and we are trying to teach our students how to tackle problems in geochemistry and crystal chemistry using the very many laboratory experimental methods available. At the same time we try to inculcate in them a healthily critical attitude towards all the “experimental results” and “data” they find in the literature. Perhaps they can become as thoroughly critical as Professor Tunell of UCLA—who has just been a visiting lecturer at Penn State—can be of thermodynamics theory. Thus, armed with a critical attitude towards all data including our own, we are slowly adding to the crystal chemical data towards the day when empirically geochemists will be able to predict what phase or phases any given composition will form under chosen “*p*” and “*t*” conditions.



RUSTUM ROY

It was in *The Atlantic Monthly* that I read recently an article on whether one can actually develop, at will, "geniuses" in our College. The author's conclusion was that though we cannot grow "geniuses" at

will, we could help bright minds address themselves to the proper problems—the most important ones of the time. This afternoon I am going to present to the bright minds around me a list of problems. I hope you will forgive me that none of them is technical—each of them is, I believe, nonetheless important to the solution of our technical problems.

The first of these is that of *motivation*. One of the reasons for giving the MSA award is to provide motivation for further work. Dr. Bowen in his characteristically expressive way when presenting Dr. Tuttle for the first award mentioned the “spurring” effect of the arrival of each issue of the *Mineralogist* on the scientific productivity of the recipient. But awards are only a part of the incentives which already exist for the research man. Beyond the intrinsic interest of his work the research man is rewarded by the publication of papers and the accompanying publicity both among his colleagues and the general scientific public; he is often rewarded financially by outside consulting arrangements. As he gets money for research projects from outside sources he becomes more and more independent of his immediate administrative environment. If incentives are good for the research man they are just as desirable for teachers. And I think that the first major problem confronting earth scientists is to find a way to provide, immediately and specifically, adequate incentives for outstanding teachers at both undergraduate and graduate levels. I sometimes wonder what effect it would have on our Journals if all the products of research (viz. papers) were published anonymously—just as all the teachers’ products (trained students) go out without a label.

The second area for some thought and action is the question of *authorship* of scientific papers. It seems to me that we cannot go on much longer with such a non-quantitative approach with so many local different ground rules. This is the cause of much misunderstanding and avoidable recrimination in the scientific community and no one seems to be tackling it. There is room here for thought by scientists, and action by various groups of scientists in experimenting with ways of establishing some uniformity of practice and perhaps some measure of quantitative-ness.

The last area is the much more complex and subtle one of *adequate acknowledgment* of the source of some of our ideas. This is a problem which is becoming both increasingly difficult and increasingly extensive as the number of meetings multiplies and inter-laboratory visits become everyday happenings. If we were able to work out a satisfactory approach we may have much more inter-laboratory cooperation and less competition. Perhaps, also, our theoretical and “teaching” colleagues may thus be recognized for their participation in experimental research, through the medium of their ideas.

PROCEEDINGS OF THE THIRTY-EIGHTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA AT ATLANTIC CITY, NEW JERSEY

C. S. HURLBUT, *Secretary*.

The thirty-eighth meeting of the Society was held on November 4-6, 1957 at Haddon Hall, Atlantic City, New Jersey. As in past years, the scientific sessions were integrated with those of the Geological Society of America and the other affiliated Societies. Of the total of thirty-one scientific sessions, two were devoted to mineralogy, one to petrology, one to crystal chemistry and four to geochemistry, at which eighty papers were presented.

The annual luncheon of the Society on November 5 was attended by 232 fellows, members and guests. This is the largest number ever to attend a Society luncheon. Following the luncheon the fifteenth presentation of the Roebling Medal was made to Walter F. Hunt and the sixth presentation of the Mineralogical Society of America Award was made to Rustum Roy.

The Retiring President, D. Jerome Fisher, addressed the Society on the afternoon of November 5. His subject was *Pegmatite Phosphates and Their Problems*. At the annual business meeting, held at 4:30 P.M., November 5, brief reports were given by the President, Treasurer, Secretary and Editor. General discussion, particularly regarding symbols for refractive indices, took place from the floor. It is the hope that in the future more members will come to the Annual Business Meeting prepared to raise questions and take part in discussion.

COUNCIL ACTION

The 1957 Council of the Society met for thirteen hours and discussed thirty-eight items of business. There are several of these items which the Council felt are of general interest and should be reported to the membership. The President in his report has mentioned most of these but two others worthy of consideration are given below.

Constitution. A committee was appointed in 1956 to study the Constitution and make suggestions that would bring it up to date. A large portion of the time of the 1957 Council was spent in considering the report of this Committee. The Council recommends many changes in the Constitution, some minor but others of major importance, which will be published in the May-June issue of the *American Mineralogist*. The membership will be asked to vote on the recommended changes in September, 1958.

One of the proposed changes that will be of interest to many members is in regard to the election of Councilors, two of whom are elected annually. It is proposed that the ballot carry the names of four nominations for Councilor and the membership be asked to vote for two.

Free reprints. As an economy measure, instituted in March, 1956, no free reprints have been given authors of papers published in the *American Mineralogist*. However, the Council voted that beginning with the January-February 1958 issue, 50 free reprints are to be given to the author of each major article and each Note published in the *American Mineralogist*.

The 1958 Council met for three hours on November 6 and discussed the following items of business:

Committee Appointments. President Goodspeed made various committee appointments which were approved by the Council.

International Mineralogical Association. Professor M. J. Buerger was appointed official

delegate to the organizational meeting of the International Mineralogical Association to be held in Madrid, Spain, 1958. Professor L. G. Berry was appointed alternate delegate.

Mineralogical Abstracts. In 1959, the Mineralogical Society of Great Britain and the Mineralogical Society of America will jointly publish the new *Mineralogical Abstracts*. The Council voted the equivalent of 500 English pounds to underwrite the establishment of this project.

Pamphlet on Careers in Mineralogy. The Council voted that the Society should provide a pamphlet on *Careers in Mineralogy*, to be distributed by the American Geological Institute and appointed Charles Milton chairman of a committee to prepare it.

Indices of Refraction Symbols. The Council voted that the Editor be instructed to use α , β , γ as index of refraction symbols, in papers published in the *American Mineralogist*.

MSA notice for museums, universities, etc. The Council instructed Professor D. J. Fisher to prepare copy for a notice giving the aim of the MSA and instructions on how to join the Society. When printed, these notices will be sent to a selected list of museums and universities, but will be available to anyone on request. An announcement of this notice is to be made in the *American Mineralogist*.

1958 COMMITTEES OF THE MINERALOGICAL SOCIETY OF AMERICA

The President wishes to remind the fellows and members of their privilege of corresponding with the officers and councilors or any of the personnel of the following committees regarding the business of the Society.

Nominating Committee for Fellows

A. W. Jolliffe, *Chairman* 56-58
G. Switzer 56-58
W. R. Foster 57-59
S. E. Clabaugh 57-59
C. O. Hutton 58-60
A. L. Anderson 58-60

Roebbling Medal Committee

Ian Campbell, *Chairman*
J. R. Goldsmith
C. A. Anderson
C. E. Tilley
R. E. Emmons

Nominating Committee for Officers

A. C. Waters, *Chairman*
G. C. Kennedy
W. F. Bradley
G. W. Bain
H. L. James

Mineralogical Society of America Award Committee

L. W. Staples, *Chairman*
E. W. Heinrich
L. H. Ahrens
W. S. Burbank
Rustum Roy

Program Committee

H. W. Fairbairn, *Chairman* 57-59
H. T. Evans 57-59
O. R. Grawe 58-60

Nomenclature Committee

C. Milton, *Chairman* 57-59
E. E. Wahlstrom 56-58
H. Winchell 57-59
C. S. Hurlbut 58-60
M. Fleischer 58-60

Board of Associate Editors

E. W. Heinrich 56-58
C. L. Christ 56-58
J. Murdoch 57-59
D. J. Fisher 58-60
G. T. Faust 58-60
R. M. Garrels 57-59

Financial Advisory Committee

E. P. Henderson, *Chairman* 56-58
A. Montgomery 57-59
M. Hooker 58-60

Auditing Committee

W. T. Pecora, *Chairman*
M. E. Mrose
F. R. Boyd

Mineralogical Abstracts Committee

L. G. Berry, *Chairman*
 A. Pabst
 M. E. Mrose

Endowment Committee

A. O. Woodford 56-58
 A. Montgomery 57-59
 J. B. Jago 58-60

Representative to AAAS

C. Tolman 57-59

*Representatives to American Geological Institute**Board of Directors*

L. R. Page 57-59
 C. Frondel 58-60

Government Relations Committee

P. F. Kerr 57-59

National Research Council

J. D. H. Donnay 56-58

Glossary Committee

C. Frondel, *Chairman*
 E. W. Heinrich
 H. R. Gault

Research Committee

E. Ingerson, *Chairman*
 J. F. Schairer
 S. Zerkoff

REPORT OF THE PRESIDENT

To the Council and Members of the Mineralogical Society of America:

Reports of your officers make it clear that our Society has had another good year as measured by material things. Our Journal, far and away the most important contribution we make towards the advancement of the mineralogical sciences, has continued to thrive under its new editor. The outstanding sacrifices made by him, and by our long-standing secretary and even longer-standing treasurer, are far too little appreciated, even by the other officers and councillors who for a few years are in more or less close contact with them.

Our Council meets but once a year. This of necessity means a considerable burden of correspondence throughout the year, and a heavy program at the meetings. For instance the retiring council alone this year had 38 items of business listed on its advance agenda. One innovation put into effect this year which seems to be of value is the requirement that all reports from committees and representatives be submitted to the Secretary by September 1. These can thus be duplicated and distributed to the Council well in advance of the meeting. This not only gives time for careful appraisal of matters well before the meeting, but permits the possibility of a limited amount of correspondence in an attempt to clear up controversial points. It is hoped that at least some of the Officers' Reports (perhaps tentative) may be submitted early in this fashion in the future.

This past year the number of committees has been larger than usual. The membership of these is listed on pp. 269-270 and 572 of Vol. 42 of our Journal. Over fifty different fellows besides the twelve on the Council have participated in these activities; in addition we have five other names among our representatives to the various societies. Thus more than seventy different fellows (or over 20% of our total) have played a direct role in keeping us functioning this year. Who says this is not a democratic organization? On behalf of our Society it is a pleasure to thank all these fellows, and particularly the Committee Chairman, for their labors.

Besides the usual committees that our Society always needs, this year we have had several extraordinary ones dealing with the following matters: Criteria for Medals and Awards, Endowment Funds, International Mineralogical Association, Lengths of Officers' Terms, Mineralogical Abstracts, and Revision of the Constitution. In the preceding

notes the Secretary has reported on the deliberations of the Council as regards some of these items; my comments on some of the others are as follows.

International Mineralogical Association. The proposal that this organization be formed was brought up in our open business meeting last year in Minneapolis. Professor Buerger was named chairman of a committee which acted with such speed that a first international meeting was held at Montreal July 16, 1957. Delegates from twelve countries besides Canada and the United States were in attendance. All continents but Africa were represented. Nine European countries including the U.S.S.R. sent delegates. The following was accomplished: 1) election of a set of three interim officers with six delegates; 2) a committee from these is preparing a constitution; 3) a meeting of delegates is scheduled to be held in Madrid in April 1958; and 4) there was discussion of needed commissions.

It seems to me that this is a perfect example to show that our membership exclusive of the Council can initiate important business. While the open meeting at Atlantic City on November 5, 1957 was satisfactory as regards attendance and discussion, and a great improvement over such meetings in the past which I have attended, nevertheless in my opinion it would have been more satisfactory had there been less time devoted to relatively negative matters such as criticism of the Council, and if more signs of a live membership making proposals for positive action to advance our science had been in evidence. What good suggestions can you make at our St Louis meeting next fall?

Length of Officers' Terms. This committee under the chairmanship of Professor Campbell prepared an outstanding report. It recommended no change as regards present customs except for two items: 1) the office of editor be appointive rather than elective; and 2) the secretary and treasurer be elected for three-year terms, with a maximum of three terms. The committee was strongly in favor of item 1, and rather luke-warm as regards item 2. After careful deliberation the Council accepted the first of these, but voted no change as regards the second. As a result, item 1 will go on the ballot next September.

Nomenclature Committee. The chairman, Professor Hutton, reported that the committee has been unable to agree on one subject on its agenda—the nomenclature of crystal forms. There are two sub-committees, one on nomenclature of feldspars, which has not yet completed its deliberations; and one on the nomenclature of clays, which seems to be bogged down because of lack of agreement. This report is at first glance discouraging; but what it really means is that we are still pretty ignorant. Facts are not sufficient to justify final conclusions.

A fresh new committee has been constituted. It may attack new problems; members with suggestions or comments should transmit them to Chairman Milton or Secretary Hurlbut. In addition this committee will cooperate with a similar British committee in connection with Mineralogical Abstracts, and also a corresponding committee of the International Mineralogical Association.

Glossary Committee. The American Geological Institute has published a glossary of geology which is now in its second printing. It is expected that a new edition will appear within a few years. If you find errors in the present edition in any section dealing with the mineralogical sciences, kindly transmit a memorandum covering these to our committee chairman, Professor Frondel.

I would call particular attention to our endowment fund. This was started by a magnificent unrestricted gift of \$45,000 by Colonel Washington A. Roebling in 1926 with the expressed wish that “—the whole, or part of it, be devoted to the publication of the monthly magazine, *The American Mineralogist*—.” By 1940, when the present treasurer took over, this fund amounted to nearly \$53,000. Since then, under the watchful eyes of our Finance Committees and the Treasurer, this amount has more than doubled. There have been only very minor gifts (since the original one) to this fund, but besides capital

gains, interest, and dividends, the fund has been increased by \$100 for each life membership (whether voluntary or due to retirement, or to selection as correspondent or M.S.A. award winner; of course only the first of these adds any "outside" money to the fund). With continued careful scrutiny of our investments plus an active campaign to increase the principal substantially, by the time of our fiftieth anniversary, our Society should be in a position to carry forward on its own resources. We should not put all the burden of trying to raise this needed money on the shoulders of the members of one committee. While each of us should report good prospects to Chairman Woodford of the Endowment Committee, it must be realized that if only half of our members sent in checks for double their annual dues for each of the next twelve years, this would add \$50,000 to our endowment funds by the time of our golden jubilee. This is an age in which organizations such as ours are very dependent on small gifts continuing over a period of years; if your dues-check is oversize, our Treasurer will understand.

In addition to the usual financial aid the Geological Society of America gives us each year to help carry the cost of publishing the *American Mineralogist*, which is very vital in our maintenance of a superior journal at a nominal subscription price, it is a pleasure to acknowledge the receipt of a generous grant from the National Science Foundation underwriting the publication costs of the current Decennial Index to our journal prepared by Dr. Ingerson. It is urged that all fellows, members, and subscribers purchase a copy of this index. Early compliance with this request will give each of us more use of it during the period when it is most valuable, and also will relieve the Society's storage and amortization problems. Even if you don't feel able to contribute to the endowment fund, surely you can help out the cause of dissemination of mineralogical literature to this extent. Why not send the Treasurer three dollars now?

The year as President has been very interesting to me; I see no reason to think that the Society has failed to survive it in good fashion. I deeply appreciate the honor conferred on me in electing me to this office. It is my one excursion into administration, and may such a thing never happen again! With confidence in the future, even though it involves doing the mineralogy of the moon, and great personal pleasure, I turn over the gavel to Professor Goodspeed.

Respectfully submitted,
D. JEROME FISHER.

REPORT OF THE SECRETARY

To the Council of the Mineralogical Society of America:

ELECTION OF OFFICERS AND FELLOWS

Six hundred and twenty ballots were cast in the election of officers, 184 by fellows and 426 by members of the Society. In addition, ten were irregular and not included. The officers elected to serve in 1958 are:

President: George E. Goodspeed, University of Washington, Seattle, Washington.

Vice-President: Ralph E. Grim, University of Illinois, Urbana, Illinois.

Secretary: C. S. Hurlbut, Jr., Harvard University, Cambridge 38, Mass.

Treasurer: Earl Ingerson, U. S. Geological Survey, Washington 25, D. C.

Editor: Lewis S. Ramsdell, University of Michigan, Ann Arbor, Michigan.

Councilors: (1958-1960) Charles Milton, U. S. Geological Survey, Washington, D. C.

Richard H. Jahns, California Institute of Technology, Pasadena, California.

According to the provisions of the Constitution, the following have been elected to fellowship:

F. Donald Bloss, University of Tennessee, Knoxville, Tennessee.

Dorothy Carroll, U. S. Geological Survey, Washington, D. C.
 George W. DeVore, University of Chicago, Chicago, Illinois.
 Herbert D. Glass, Illinois State Geological Survey, Urbana, Illinois.
 Donald Lee Graf, Illinois State Geological Survey, Urbana, Illinois.
 Marjorie Hooker, U. S. Geological Survey, Washington, D. C.
 William Scott MacKenzie, Dept. of Geology, University of Manchester, Manchester 13, England.
 Helen Ruth Stobbe, Smith College, Northampton, Massachusetts.
 Alvin Van Valkenburg, National Bureau of Standards, Washington, D. C.
 Charles Edward Weaver, Shell Oil Company, Houston, Texas.
 E. Joseph Weiss, University of Texas, Austin, Texas.

MEMBERSHIP STATISTICS

November 1, 1957

	1956	1957	Gain	Loss
Correspondents.....	4	3	0	1
Fellows.....	345	356	17	6
Members.....	1,014	1,075	131	70
Subscribers.....	966	1,041	128	53
	<hr/> 2,329	<hr/> 2,475	<hr/> 276	<hr/> 130

The above figure shows a net gain of 11 fellows, 61 members and 75 subscribers. Considering the four groups together, there is a gain of 146, giving a total of 2,475.

During 1957, the Society lost through death six fellows: G. D. Louderback, Berkeley, California; A. L. Parsons, Toronto, Canada; J. C. Rabbitt, Washington, D. C.; A. F. Rogers, Berkeley, California; S. J. Shand, Edinburgh, Scotland; B. Wasserstein, Pretoria, South Africa. Also through death, the Society lost F. Slavík, of Praha, Czechoslovakia, a correspondent.

Respectfully submitted,
 C. S. HURLBUT, JR., *Secretary*

REPORT OF THE TREASURER FOR 1957

To the Council of the Mineralogical Society of America:

Your Treasurer submits herewith his report for the fiscal year beginning August 1, 1956, and ending July 31, 1957.

RECEIPTS

Dues and subscriptions.....	\$13,050.19
Sale of back numbers.....	1,383.39
Authors' charges on reprints.....	2,615.17
Interest and dividends from endowment.....	6,293.46
Geological Society of America aid for printing the Journal.....	8,000.00
Advertising.....	713.76
Sale of Index, vols. 21-30.....	10.00
Sale of Index, vols. 1-20.....	4.00
	<hr/> \$32,069.97
Cash on hand, August 1, 1956.....	4,120.38
	<hr/> \$36,190.35

DISBURSEMENTS

Printing and distribution of the Journal (6 issues).....	\$15,708.83
Printing and distribution of reprints.....	2,481.77
Honoraria to Editor, Secretary and Treasurer.....	1,250.00
Clerical assistance.....	1,168.25
Printing and stationery.....	520.61
Program and abstracts (1956).....	225.00
Roebling Medal (1956).....	134.65
Postage and express.....	696.15
Expenses of officers to 1956 meetings.....	151.65
New securities purchased.....	10,018.18
Commission on new securities.....	37.50
Tax on new securities.....	1.08
Office equipment.....	435.90
Safety deposit box.....	7.15
Refunds.....	19.46
Telephone and telegrams.....	6.39
Committee expenses.....	5.03
Mineralogical Society of America Award certificate.....	7.00
Special certificate of appreciation to Walter F. Hunt.....	35.00
Contribution to American Geological Institute.....	516.00
Expenses in preparation of Index to volumes 31-40.....	1,126.20
Checks returned.....	107.20
	<hr/>
	\$34,658.82
Cash on hand, July 31, 1957.....	1,531.53
	<hr/>
	\$36,190.35

The endowment funds of the Society as of July 31, 1957, consist of the following securities:

BONDS

6M Atlantic Coast Line, 4½.....	\$ 5,257.50
5M New York Central, 5.....	4,300.00
5M Southern Railway, 5.....	5,743.75
	<hr/>
	\$ 15,301.25

PREFERRED STOCKS

500 Union Pacific, 4.....	\$ 4,570.25
200 Southern California Edison, 4.88.....	5,250.00
150 Penn-Texas, 1.60.....	4,487.50
60 Jones and Laughlin, A, 5.....	4,987.50
55 United States Steel, 7.....	6,946.20
50 Virginia Electric and Power, 5.....	5,942.50
40 Potomac Electric Power, 2.44.....	2,000.00
10 Consolidated Edison, 5.....	1,066.64
	<hr/>
	\$ 35,250.59

COMMON STOCKS

346 Potomac Electric Power.....	\$ 4,966.73
215 Columbia Gas.....	3,436.25
200 Greyhound Corporation.....	2,300.00
168 Standard Oil of New Jersey.....	1,444.84
150 Spencer Kellogg.....	3,775.00
150 Consolidated Denison.....	3,096.00
100 Buckeye Steel.....	3,800.00
100 Columbus and Southern Ohio Electric.....	2,087.50
100 Diana Stores.....	1,250.00
100 Pittsburgh and West Virginia.....	2,787.50
83 Kroger Company.....	1,990.00
75 American Telephone and Telegraph.....	10,117.25
60 United Fruit.....	3,067.50
50 Chesapeake and Ohio.....	2,368.75
50 Phelps Dodge.....	1,975.00
50 Sinclair Oil.....	2,968.75
40 Plymouth Cordage.....	2,050.00
30 U. S. Playing Card.....	2,411.25
24 Public Service Electric and Gas.....	728.40
	<hr/>
	56,620.72
	<hr/>
	\$107,172.56

Respectfully submitted,
EARL INGERSON, *Treasurer*

REPORT OF THE AUDITING COMMITTEE

To the President of the Mineralogical Society of America:

The Auditing Committee has examined and verified the accounts of the Treasurer of the Mineralogical Society of America for the fiscal year beginning August 1, 1956, and ending July 31, 1957. The securities listed in the Treasurer's report, with all future coupons on the coupon bonds attached, are in the safety deposit box at the 17th and G Street Branch of the Riggs National Bank in Washington, D. C.

Respectfully submitted,
C. A. ANDERSON
H. L. JAMES
MARGARET D. FOSTER, *Chairman*

REPORT OF COMMITTEE ON ENDOWMENTS

The Mineralogical Society of America needs more endowment. The present endowment of about \$100,000 should be increased to \$300,000, to provide for our present operations. However, as our costs are constantly going up, and as some expansion in our operations seems necessary, especially in connection with the proposed abstract journal, an increase of the endowment to about \$400,000 would be most desirable. The need is urgent, and gifts large and small will be welcomed at any time.

One attractive device, widely used, is to give stock that has increased markedly in value. The donor avoids paying capital gains tax, and can take as a tax deduction the full market value of the stock. Of course, the deduction cannot exceed the allowable limit of 20 per cent of adjusted gross income during the tax year.

Fellows and members are also urged to consider the Society when writing their wills,

and to bring the Society's needs to the attention of interested friends who might make bequests for the advancement of mineralogy. Property left to the Mineralogical Society of America is exempt from inheritance and estate taxes. Bequests should be made to the Mineralogical Society of America, Inc., Washington 25, D. C.

Committee on Endowments

A. O. WOODFORD, *Chairman*

C. FRONDEL

C. B. SLAWSON

REPORT OF THE EDITOR FOR 1957

To the Council of the Mineralogical Society of America:

The 1957 volume of *The American Mineralogist* contains 940 pages, compared with 974 for 1956. This averages about 160 pages per bimonthly issue. There are 65 leading articles, and 39 shorter papers, making a total of 104 published manuscripts. These were received from 162 contributors, representing 37 schools, institutions, and industrial laboratories; 27 in the United States and 10 in foreign countries. Four new minerals were described in detail for the first time. There were 23 book reviews, 8 notices of publications, and 20 miscellaneous notes. Dr. M. Fleischer continued his valuable section of New Mineral Names, New Data and Discredited Minerals, with 75 entries. Our Society is greatly indebted to Dr. Fleischer for this service. We appreciate not only the valuable information but also his pertinent comments.

As in former years, the Geological Society of America has continued its liberal financial support, defraying a very substantial portion of the printing costs of the Journal. We are grateful for this assistance and wish to express our appreciation.

In recent years there have been at times quite large backlogs of manuscripts on hand, so that in some cases there was too long an interval between receipt of a manuscript and its publication. When Dr. Hunt retired as Editor, he had this situation under control, as shown by the fact that after the January-February, 1957, manuscripts had gone to the printer there were only 25 additional manuscripts on hand. To keep the backlog under control, the Council in 1956 authorized a special supplement to the November-December, 1957, issue. Papers from Harvard University were to be held up for this supplement, thus leaving more room in the regular issues for other manuscripts.

By midsummer, however, because of the comparatively small number of manuscripts on hand, and the small number anticipated from Harvard, the idea of a supplement was abandoned, and it was decided to put the Harvard papers in the regular November-December issue. This decision was also influenced by the fact that in the three-months period from August through October, 1956, only five manuscripts were accepted for publication.

Subsequent developments show how unpredictable the supply of manuscripts can be. The number from Harvard increased to 14 leading articles and 5 shorter notes, making a large November-December issue. Moreover, in contrast to the 5 manuscripts received in the three months August through October last year, this year in the same period 27 were received. This about doubles our backlog and will require considerably larger issues for the first two or three numbers of 1958 to get back to normal. However, few of these manuscripts will have to wait more than eight months. In this connection, it might be well to consider the following facts. Manuscripts are sent to the printer about two months before the issue is out, for example, about January 12 for the March-April issue. But these manuscripts are being assembled, marked for the printer, and the arrangement and size of illustrations figured out during the preceding two weeks, beginning about December 28. Thus any manuscript arriving after January 1 could not appear before the May-June issue, nearly six months later.

However, since the editor does not wish to completely clear out all manuscripts on hand, it could very well be the July-August issue, nearly eight months later. This delay can be considered quite normal, unless the editor made it a policy to send in all manuscripts received up to a certain deadline. This might mean a very large issue, with a chance of having the following issue a very small one.

The new editor wishes to express his thanks for the help he has received from the Editor Emeritus, Dr. Hunt. The fact that he has been available for consultation on many questions has made the editorial task much easier. The George Banta Company Inc., publishers of the Journal, also deserve mention. Their efficient cooperation and great experience have made the change in editors possible with very few errors of commission or omission.

There should also be acknowledged the help of the Associate Editors, Drs. W. F. Bradley, C. L. Christ, R. M. Garrells, E. Wm. Heinrich, J. Murdoch and F. J. Turner. Their prompt reading of manuscripts and reporting on their acceptability, and their suggestions to the authors, all constitute an important service. Similar help has also been received from Drs. G. W. Brindley, R. M. Denning, D. McConnell, A. Pabst, and H. Winchell. Ten manuscripts were rejected, and quite a number were revised after receiving criticisms and suggestions.

As already stated, there are enough manuscripts on hand to provide for several larger issues early in 1958.

A summary of the distribution of subject matter in Vol. 42 is shown in the following table.

DISTRIBUTION OF SUBJECT MATTER IN VOLUME 42

Subjects	Articles	Pages	Per Cent of Total
Leading articles*			
Descriptive mineralogy and paragenesis.	19		
Chemical mineralogy and geochemistry.	8		
X-ray analysis and crystal structure.	6		
Geometrical crystallography.	1		
Petrography.	4		
Differential thermal analysis.	4		
Physical properties.	9		
Memorials.	3		
Miscellaneous.	11		
	65	730	79.2
Short articles.	39	116	
Notes.	23	5	
Proceedings of Society.	1	26	
Book reviews and notices.	31	18	
Abstracts of new mineral names.	65	26	
	201	921	100.0
Total entries.		921	
Index, Title page, Table of Contents.		19	
Grand total.		940	

* Leading articles average 11.2 printed pages.

LIST OF FORMER OFFICERS AND MEETING PLACES

By recommendation of the Council, a complete list of past officers is printed in the proceedings of the annual meeting of the Society:

HONORARY PRESIDENTS

Edward S. Dana 1925-1935

Charles Palache 1949-1954

Edward H. Kraus 1955-

PRESIDENTS

1920 Edward H. Kraus
 1921 Charles Palache
 1922 Thomas L. Walker
 1923 Edgar T. Wherry
 1924 Henry S. Washington
 1925 Arthur S. Eakle
 1926 Waldemar T. Schaller
 1927 Austin F. Rogers
 1928 Esper S. Larsen
 1929 Arthur L. Parsons
 1930 Herbert E. Merwin
 1931 Alexander H. Phillips
 1932 Alexander N. Winchell
 1933 Herbert P. Whitlock
 1934 John W. Wolff
 1935 Clarence S. Ross
 1936 William S. Bayley
 1937 Norman L. Bowen
 1938 Ellis Thomson
 1939 Max N. Short
 1940 William F. Foshag
 1941 Frederick E. Wright
 1942 Arthur F. Buddington
 1943 John F. Schairer
 1944 R. C. Emmons
 1945 Kenneth K. Landes
 1946 Paul F. Kerr
 1947 M. J. Buerger
 1948 M. A. Peacock
 1949 John W. Gruner
 1950 George Tunell
 1951 A. Pabst
 1952 Michael Fleischer
 1953 J. D. H. Donnay
 1954 Sterling B. Hendricks
 1955 Harry H. Hess
 1956 Clifford Frondel
 1957 D. Jerome Fisher

VICE-PRESIDENTS

1920 Thomas L. Walker
 1921 Waldemar T. Schaller
 1922 Frederick A. Canfield
 1923 George F. Kunz
 1924 Washington A. Roebling
 1925 Herbert P. Whitlock
 1926 George Vaux, Jr.
 1927 George L. English
 1928 Lazard Cahn
 1929 Edward Wigglesworth
 1930 John E. Wolff
 1931 William F. Foshag
 1932 Joseph L. Gillson
 1933 Frank B. Guild
 1934 William A. Tarr
 1935 Ellis Thomson
 1936 Harold L. Alling
 1937 H. V. Ellsworth
 1938 Kenneth K. Landes
 1939 Burnham S. Colburn
 1940 Ian Campbell
 1941 William J. McCaughey
 1942 Martin J. Buerger
 1943 John W. Gruner
 1944 Harry Berman
 1945 George Tunell
 1946 S. B. Hendricks
 1947 Carl Tolman
 1948 Adolf Pabst
 1949 J. D. H. Donnay
 1950 Ralph E. Grim
 1951 Michael Fleischer
 1952 J. D. H. Donnay
 1953 Sterling B. Hendricks
 1954 Harry H. Hess
 1955 Clifford Frondel
 1956 D. Jerome Fisher
 1957 George E. Goodspeed

SECRETARIES

1920-1922 Herbert P. Whitlock
 1923-1933 Frank R. Van Horn
 1933-1934 Albert P. Peck
 1934-1944 Paul F. Kerr
 1944- C. S. Hurlbut, Jr.

TREASURERS

1920-1923 Albert B. Peck
 1924-1929 Alexander H. Phillips
 1929-1930 Albert B. Peck
 1930-1940 Waldemar T. Schaller
 1941- Earl Ingerson

EDITORS

1920-1921 Edgar T. Wherry
 1922-1956 Walter F. Hunt
 1957-Lewis S. Ramsdell

COUNCILORS

1920 Arthur S. Eakle, Frank R. Van Horn, Fred E. Wright, Alexander H. Phillips.
 1921 Frank R. Van Horn, Fred E. Wright, Alexander H. Phillips, Austin F. Rogers.
 1922 Fred E. Wright, Alexander H. Phillips, Austin F. Rogers, Thomas L. Watson.
 1923 Alexander H. Phillips, Austin F. Rogers, Thomas L. Watson, Esper S. Larsen.
 1924 Austin F. Rogers, Thomas L. Watson, Esper S. Larsen, Arthur L. Parsons.
 1925 Thomas L. Watson, Esper S. Larsen, Arthur L. Parsons, William F. Foshag.
 1926 Esper S. Larsen, Arthur L. Parsons, William F. Foshag, William A. Tarr.
 1927 Arthur L. Parsons, William F. Foshag, William A. Tarr, Alexander N. Winchell.
 1928 William F. Foshag, William A. Tarr, Alexander N. Winchell, Ellis Thomson.
 1929 William A. Tarr, Alexander N. Winchell, Ellis Thomson, Clarence S. Ross.
 1930 Alexander N. Winchell, Ellis Thomson, Clarence S. Ross, Paul F. Kerr.
 1931 Ellis Thomson, Clarence S. Ross, Paul F. Kerr, William S. Bayley.
 1932 Clarence S. Ross, Paul F. Kerr, William S. Bayley, William J. McCaughey.
 1933 Paul F. Kerr, William S. Bayley, William J. McCaughey, Kenneth K. Landes.
 1934 William S. Bayley, William J. McCaughey, Kenneth K. Landes, E. P. Henderson.
 1935 William J. McCaughey, Kenneth K. Landes, E. P. Henderson, J. F. Schairer.
 1936 Kenneth K. Landes, E. P. Henderson, J. F. Schairer, Arthur F. Buddington.
 1937 E. P. Henderson, J. F. Schairer, Arthur F. Buddington, Arthur P. Honess.
 1938 J. F. Schairer, Arthur F. Buddington, Arthur P. Honess, R. C. Emmons.
 1939 Arthur F. Buddington, Arthur P. Honess, R. C. Emmons, Carl Tolman.
 1940 Arthur P. Honess, R. C. Emmons, Carl Tolman, D. Jerome Fisher.
 1941 R. C. Emmons, Carl Tolman, D. Jerome Fisher, Martin A. Peacock.
 1942 Carl Tolman, D. Jerome Fisher, Martin A. Peacock, Adolf Pabst.
 1943 D. Jerome Fisher, Martin A. Peacock, Adolf Pabst, C. S. Hurlbut, Jr.
 1944 Martin A. Peacock, Adolf Pabst, Michael Fleischer, S. J. Shand.
 1945 Adolf Pabst, Michael Fleischer, S. J. Shand, R. E. Grim.
 1946 Michael Fleischer, S. J. Shand, R. E. Grim, Joseph Murdoch.
 1947 S. J. Shand, R. E. Grim, Joseph Murdoch, H. H. Hess.
 1948 R. E. Grim, Joseph Murdoch, H. H. Hess, Clifford Frondel.
 1949 Joseph Murdoch, H. H. Hess, Clifford Frondel, Lewis S. Ramsdell.
 1950 H. H. Hess, Clifford Frondel, Lewis S. Ramsdell, E. F. Osborn.
 1951 Clifford Frondel, Lewis S. Ramsdell, E. F. Osborn, George T. Faust.
 1952 Lewis S. Ramsdell, E. F. Osborn, George T. Faust, Victor T. Allen.
 1953 E. F. Osborn, George T. Faust, Victor T. Allen, C. Osborne Hutton.
 1954 George T. Faust, Victor T. Allen, C. Osborne Hutton, Felix Chayes.
 1955 Victor T. Allen, C. Osborne Hutton, Felix Chayes, L. G. Berry.
 1956 C. Osborne Hutton, Felix Chayes, L. G. Berry, C. B. Slawson, A. O. Woodford.
 1957 Felix Chayes, L. G. Berry, C. B. Slawson, A. O. Woodford, Samuel S. Goldich.

Annual Meeting Places

1920 Chicago, Illinois	1939 Minneapolis, Minnesota
1921 Amherst, Massachusetts	1940 Austin, Texas
1922 Ann Arbor, Michigan	1941 Boston, Massachusetts
1923 Washington, D. C.	1942 No meeting held
1924 Ithaca, New York	1943 No meeting held
1925 New Haven, Connecticut	1944 No meeting held
1926 Madison, Wisconsin	1945 Pittsburgh, Pennsylvania
1927 Cleveland, Ohio	1946 Chicago, Illinois
1928 New York, N. Y.	1947 Ottawa, Canada
1929 Washington, D. C.	1948 New York, N. Y.
1930 Toronto, Canada	1949 El Paso, Texas
1931 Tulsa, Oklahoma	1950 Washington, D. C.
1932 Cambridge, Massachusetts	1951 Detroit, Michigan
1933 Chicago, Illinois	1952 Boston, Massachusetts
1934 Rochester, New York	1953 Toronto, Canada
1935 New York, N. Y.	1954 Los Angeles, California
1936 Cincinnati, Ohio	1955 New Orleans, Louisiana
1937 Washington, D. C.	1956 Minneapolis, Minnesota
1938 New York, N. Y.	1957 Atlantic City, New Jersey

RECIPIENTS OF THE ROEBLING MEDAL

Charles Palache, December 1937	Herbert E. Merwin, November 1949
Waldemar T. Schaller, December 1938	Norman L. Bowen, November 1950
Leonard James Spencer, December 1940	Fred E. Wright, November 1952
Esper S. Larsen, Jr., December 1941	William F. Foshag, November 1953
Edward H. Kraus, February 1945	Cecil Edgar Tilley, November 1954
Clarence S. Ross, December 1946	Alexander N. Winchell, November 1955
Paul Niggli, December 1947	Arthur F. Buddington 1956
William Lawrence Bragg, November 1948	Walter F. Hunt 1957

RECIPIENTS OF THE MINERALOGICAL SOCIETY OF AMERICA AWARD

Orville Frank Tuttle, November 1951	Julian R. Goldsmith, November 1955
Frederick H. Stewart, November 1952	George C. Kennedy 1956
L. H. Ahrens, November 1953	Rustum Roy 1957
Hatten S. Yoder, Jr., November 1954	

1957 ANNUAL MEETINGS AT ATLANTIC CITY, NEW JERSEY

The meetings of the following Societies were held on November 4-6, 1957.

- The Geological Society of America—70th
- The Paleontological Society—49th
- The Mineralogical Society of America—38th
- Society of Economic Geologists—38th
- Society of Vertebrate Paleontology—17th
- Geochemical Society—2nd
- Association of Geology Teachers

The complete program listed titles and abstracts of 280 papers. Of these 130 seemed to be of special interest to members of The Mineralogical Society of America. Authors and titles of these papers are listed below. Since by Council action the abstracts will not be reprinted in *The American Mineralogist*, references are given to the *Bulletin of the Geological*

Society of America, Vol. 68, Number 12, Part 2, December 1957, pp. 1693–1816 where the abstracts of all the papers of the various societies are reprinted, arranged alphabetically by authors.

PAPERS OF SPECIAL MINERALOGICAL INTEREST

- JOHN A. S. ADAMS AND KEITH RICHARDSON: *Thorium, uranium, and potassium contents of bauxites*. Page 1693.
- VICTOR T. ALLEN: *Minerals in laterites in the state of Bolivar, Venezuela*. Page 1693.
- LLOYD L. AMES, JR.: *Chemical analyses of the inclusion fluids in a group of New Mexico minerals*. Page 1694.
- L. L. AMES, JR. AND L. B. SAND: *Factors affecting maximum hydrothermal stability in montmorillonites*. Page 1695.
- G. C. AMSTUTZ: *Genesis of spilitic rocks and mineral deposits*. Page 1695.
- G. C. AMSTUTZ: *Natural arseno-sulfide glass*. Page 1696.
- DANIEL E. APPLEMAN: *Crystal-chemical study of johannite*. Page 1696.
- G. E. ASHBY, R. C. KELLAGHER, AND W. A. CHISHOLM: *Apparatus for the study of electron trapping in minerals*. Page 1697.
- WAYNE U. AULT: *Geochemical processes and sulfur-isotope fractionation*. Page 1697.
- H. G. BACHMANN: *Crystal-chemical studies of fibrous calcium-sodium vanadates*. Page 1698.
- H. L. BARNES: *Trace-element distribution in shales near the Hanover, New Mexico, mining area*. Page 1699.
- PAUL B. BARTON, JR., AND GUNNAR KULLERUD: *Preliminary report on the system FeS-ZnS-S and implications regarding the use of the sphalerite geothermometer*. Page 1699.
- WILLIAM A. BASSETT: *Copper vermiculites from Northern Rhodesia*. Page 1700.
- F. R. BOYD AND J. F. SCHAIRER: *System MgSiO₃-CaMgSi₂O₆*. Page 1703.
- RUSSELL A. BRANT: *Coal resources studies in Ohio*. Page 1703.
- GEORGE BRUNTON, H. STEINFINK, AND CARL W. BECK: *Crystal structure of callaghanite Cu₈Mg₈(CO₃)₄(OH)₂₄·8H₂O*. Page 1704.
- W. M. CADY AND A. H. CHIDESTER: *Magmatic relations in northern Vermont and southern Quebec*. Page 1705.
- TSIAI-HWA J. CHOW AND C. C. PATTERSON: *Isotopic composition of lead in manganese nodules*. Page 1708.
- C. L. CHRIST AND JOAN R. CLARK: *Nature of the polyions in some borate minerals*. Page 1708.
- S. E. CLABAUGH AND V. E. BARNES: *Origin of central Texas vermiculite deposits*. Page 1709.
- ROBERT R. COMPTON: *Conversion of amphibolites to charnockitic rocks in the Santa Lucia Mountains, California*. Page 1711.
- FRANK DACHILLE AND RUSTUM ROY: *Silica structure studies. VII: The high-pressure region of model and half-breed derivatives*. Page 1713.
- PAUL E. DAMON AND J. LAURENCE KULP: *Argon in mica and the age of the Beryl Mountain pegmatite, New Hampshire*. Page 1713.
- D. F. DAVIDSON AND R. A. GULBRANDSEN: *Selenium in the Phosphoria formation in Idaho, Wyoming, Utah, and Montana*. Page 1714.
- E. T. DEGENS, E. G. WILLIAMS, AND M. L. KEITH: *Geochemical criteria for distinguishing marine from fresh-water shales*. Page 1715.
- L. DOLAR-MANTUANI: *Concrete aggregate examination by prolonged copper-nitrate staining test*. Page 1717.
- JOHN B. DROSTE, GEORGE W. WHITE, AND ALBERT E. VATTER: *Electron micrography of tills*. Page 1719.

- RUSSELL R. DUTCHER, CHARLES L. TROTTER, AND WILLIAM SPACKMAN, JR.: *Petrographic examination of coals from the Arctic slope of Alaska*. Page 1719.
- WALTER R. ECKELMANN, J. LAURENCE KULP, AND ARTHUR R. SCHULERT: *Geochemistry of Sr⁹⁰*. Page 1720.
- A. E. J. ENGEL AND C. PATTERSON: *Isotopic composition of lead in Leadville limestone, hydrothermal dolomite and associated ore*. Page 1723.
- CELESTE G. ENGEL AND ROBERT P. SHARP: *Chemical data on desert varnish*. Page 1723.
- EDWIN S. ERICKSON, JR., AND THOMAS F. BATES: *Evaluation of the chemical and mineralogical characteristics of a uraniferous lignite deposit from Harding County, South Dakota*. Page 1724.
- R. B. FERGUSON: *Subsolidus phase relations in the alkali feldspars*. Page 1725.
- ALBERT WILLIAM FORSLEV: *Geochemical study of some late Wisconsin tills*. Page 1727.
- MARGARET D. FOSTER: *Interpretation of the compositions of trioctahedral micas*. Page 1729.
- IRVING FRIEDMAN AND ROBERT L. SMITH: *Origin of water in some volcanic glasses*. Page 1730.
- CLIFFORD FRONDEL: *Polymorphism in cronstedtite*. Page 1731.
- ALFRED J. FRUEH: *Electrical properties of some sulfide minerals*. Page 1731.
- R. M. GARRELS: *Some free-energy values from geologic relations*. Page 1732.
- R. M. GARRELS, P. B. HOSTETLER, C. L. CHRIST, AND A. D. WEEKS: *Stability of uranium, vanadium, copper, and molybdenum minerals in natural waters at low temperatures and pressures*. Page 1732.
- PAUL W. GAST AND LEON E. LONG: *Absolute age determinations from the basement rocks of the Beartooth Mountains and Bighorn Mountains*. Page 1732.
- F. P. GLASSER AND E. F. OSBORN: *Equilibrium between the metasilicates and orthosilicates of magnesium and manganese*. Page 1735.
- JULIAN R. GOLDSMITH AND DONALD L. GRAF: *Structural and compositional variations in some natural dolomites*. Pages 1735.
- H. D. GOODE AND C. S. ROBINSON: *Lithologic and structural controls of uranium deposition in the Hulett Creek mining area, Crook County, Wyoming*. Page 1736.
- DONALD L. GRAF, COLIN R. BLYTH, AND ROSEMARIE S. STEMMLER: *Mixed-layer effects in the rhombohedral carbonates*. Page 1737.
- L. B. HALFERDAHL: *Chemical and physical properties of chloritoid*. Page 1740.
- R. IAN HARKER: *System MgO-CO₂-argon, and the effect of inert pressure on certain types of hydrothermal reaction*. Page 1741.
- JOHN A. HARRISON: *Comparison of methods of petrographic analysis and their relation to the coking character of coal*. Page 1742.
- E. WM. HEINRICH AND A. A. GIARDINI: *Brown Derby pegmatites, Colorado. I: Columbite and stibiotantalite*. Page 1744.
- FRED A. HILDEBRAND, MAXWELL K. CARRON, AND HARRY J. ROSE, JR.: *Re-examination of rhabdophane (scovillite) from Salisbury, Connecticut*. Page 1744.
- V. G. HILL AND RUSTUM ROY: *Silica structure studies. V: Tridymites*. Page 1745.
- HEINRICH D. HOLLAND: *Thermochemical data, mineral associations, and the Lindgren classification of ore deposits*. Page 1745.
- WILLIAM T. HOLSER: *Space groups, plane groups, and twin symmetry*. Page 1746.
- CLIFFORD A. HOPSON: *Origin of lamprophyres associated with the Chelan batholith, Washington*. Page 1747.
- RICHARD H. HOWE AND C. WAYNE BURNHAM: *Preliminary experiments on the transport of silica in water at high temperatures and pressures*. Page 1747.
- W. T. HUANG: *Origin of sillimanite rocks by alumina metasomatism, Wichita Mountains, Oklahoma*. Page 1748.

- JAMES D. HUME: *Stratigraphic correlation using spectrochemical analyses*. Page 1749.
- CHARLES T. ILLSLEY: *Hydrogeochemical exploration for uranium in the Mt. Spokane area, Washington*. Page 1750.
- JOHN IMBRIE AND ARIE POLDERVAART: *Normative analysis of fine-grained sedimentary rocks*. Page 1750.
- JOHN INGOLD AND R. C. DEVRIES: *Phase transitions in sodium tungsten bronze*. Page 1751.
- RICHARD H. JAHNS AND C. WAYNE BURNHAM: *Preliminary results from experimental melting and crystallization of Harding, New Mexico, pegmatite*. Page 1751.
- M. L. JENSEN: *Significance of S^{32}/S^{34} ratios on the origin of sulfides in uranium deposits of the Colorado Plateau*. Page 1752.
- HENRY L. JICHA, JR.: *Hydrothermal zoning of lead in the manganese ores of the Luis Lopez district, Socorro County, New Mexico*. Page 1753.
- LEWIS H. KING AND ALEX R. CAMERON: *Petrographic examination of coal pellets prepared by compressing plasticized particles of crushed coal*. Page 1754.
- HARRY KLEMIC, A. V. HEYL, A. R. TAYLOR, AND JEROME STONE: *Rare-earth deposit at the Scrub Oaks mine, Morris County, New Jersey*. Page 1754.
- CYRUS KLINGSBERG AND RUSTUM ROY: *System Mn-O-OH*. Page 1755.
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NOTES AND NEWS

FORMATION AND PROPERTIES OF SYNTHETIC THORITE CRYSTALS*

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Naturally occurring tetragonal thorite (ThSiO_4) is usually found in various states of metamictness as shown by its poor x-ray diffraction pattern, weak to absent birefringence, low refractive indices, and low density. Pabst has shown that progressive changes in these properties (except birefringence) occur with heating (Pabst, 1952). However, because of the complex nature of the annealing process it is not a simple matter to recognize the properties of non-metamict tetragonal thorite.

Euhedral crystals of tetragonal thorite up to 1 mm. in diameter have been grown from a 55 mole % ThF_4 -45 mole % KThF_6 eutectic mixture which melts at 875°C . (Asker, Segnit, and Wylie, 1952). To approximately 0.2 g. of this mixture, 0.11 g. of powdered ThO_2 and 0.04 g. of powdered vitreous silica were added. The contents were placed in a $\frac{1}{4}$ " O.D. \times 1.5" Monel cup, an argon atmosphere introduced and lid welded to the top of the cup. The sample was then heated in a muffle furnace for 13 days at 920°C . and slowly cooled to room temperature over a period of 2 days. The thorite crystals formed could be separated by prying the surrounding material away with a razor blade.

The transparent colorless crystals are approximately equi-dimensional square di-pyramids, prism faces are present only as narrow bands. Dichroism is present, X=pale green, Z=blue-green, $Z > X$. Refractive indices for sodium light are: $\omega = 1.823$, $\epsilon = 1.888$, ± 0.003 . It is interesting to note that there are few reported occurrences of natural thorite with optical properties similar to this synthetic preparation. The detrital crystals from Nettuno, Rome examined by Bonatti and Gallitelli (Bonatti and Gallitelli, 1951), are believed to be perfect and unaltered, contain only a "small amount" of uranium, and have slightly higher refractive indices with $\omega = 1.837$ and $\epsilon = 1.898$. Hutton determined the refractive indices on crystals of uranothorite (11.5 wt. % UO_2) from South Island, New Zealand to be $\alpha = 1.82$, $\gamma = 1.84$ (Hutton, 1950). Pabst has obtained single crystal x-ray diffraction photographs of Hutton's crystals and interpreted them to represent unaltered material, although a streaking along "powder arcs" is pointed out (Pabst, 1951).

Several synthetic thorite crystals weighing 8.42 mg. were mechanically cleaned and their volume determined by measuring the displacement of the meniscus of butyl phthalate in a precision-bore glass capillary. The

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

density at 25° C. = 6.70 ± 0.1 which compares favorably with the theoretical x -ray density of 6.67 ± 0.01 .

Weissenberg photographs taken on a selected single crystal showed sharp diffraction maxima indicative of well-formed crystals. The cell dimensions determined from these photographs are:

$$a_0 \ 7.17 \text{ \AA} \pm 0.03 \text{ \AA}$$

$$c_0 \ 6.43 \text{ \AA} \pm 0.03 \text{ \AA}$$

Cell dimensions determined from precision powder photographs are:

$$a_0 \ 7.142 \text{ \AA} \pm 0.004 \text{ \AA}$$

$$c_0 \ 6.327 \text{ \AA} \pm 0.003 \text{ \AA}$$

The detailed results of structural x -ray diffraction studies of this material have been prepared in collaboration with Elizabeth Gebert of this laboratory and appear.

REFERENCES

- ASKER, W. J., SEGNI, E. R., AND WYLIE, A. W. (1952), The Potassium Thorium Fluorides: *Jour. of the Chem. Soc. Pt. IV*, 4473.
 BONATTI, S., AND GALLITELLI, P. (1951), Sulla Torite di Nettuno (Roma): *Atti Soc. toscani Sci. Nat. (Pisa) Mem. (Series A)*, **57**, 182-183.
 HUTTON, C. OSBORNE (1950), Studies of Heavy Detrital Minerals: *Geol. Soc. Am., Bull.*, **61**, 678.
 PABST, A. (1951), X-Ray Examination of Uranothorite: *Am. Mineral.*, **36**, 557-562.
 PABST, A. (1952), The Metamic State: *Am. Mineral.*, **37**, 145-153.

THE AMERICAN MINERALOGIST, VOL. 43, MARCH-APRIL, 1958

A SIMPLE FUSION METHOD FOR DETERMINATION OF PLAGIOCLASE FELDSPAR FROM THIN SECTION

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The procedure described below is essentially a modification of the method described by Foster (1955) for determination of plagioclase feldspars by fusion. It is essential in this method to ascertain that the material to be melted is free from inclusions which would cause variation of the refractive index of the glass. Examination of a thin section of the plagioclase will show whether or not that particular section is free of included material. Therefore, it is necessary to be able to fuse a particular section of plagioclase by a method which should be simple to carry out on apparatus readily available to any petrographer.

This method requires that a small flake of the feldspar is melted and rapidly cooled to a glass. This can be done by fusion of the feldspar at the tip of an electrode from which a discharge is passing.

We use a 12 volt battery connected through a switch to the primary terminals of a small induction coil. The coil was obtained cheaply from Government Disposals; it is designated as "Coil, Booster, Battery Operated, Type C1, 24 volts D.C.". This gives a good spark with the 12 volt battery.

One secondary terminal of this coil is connected to a suitable mounted,

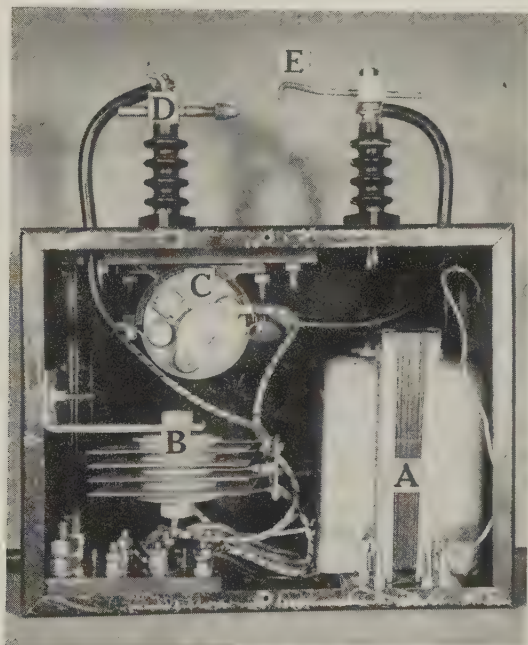


FIG. 1. Apparatus with back cover removed. A=transformer. B=rectifier. C=coil. D=chuck with Pt wire. E=adjustable electrode. Length of case is 9 inches.

insulated electrode which may be just a wire with a pointed end. The other lead from the induction coil is left so that it may be connected at will to the other electrode. This electrode is a piece of platinum wire, about an inch long, mounted in the end of a glass tube (as used for borax bead tests). This glass tube is held in a small clamp so that it may be removed. The end of the platinum wire is bent back a little to carry the feldspar flake.

Procedure: The selected feldspar crystal is removed from the thin section and carefully transferred to the platinum wire. The switch is closed and the spark allowed to pass until the specimen melts and glows brightly. The small glass mass cools very rapidly, but if difficulty in

freezing the melt is experienced, cooling could be speeded up by blowing a jet of cold air onto it. However, so far the author has had no difficulty in this regard. The platinum wire mount is removed and the bead is inspected under the microscope to ensure that it is wholly isotropic. If not, it is returned to the arc for a little longer. Experiment soon shows the most useful distance apart for the electrodes; the platinum can be readily softened, though it is wise to avoid this.

On formation of a glass bead this is then broken away from the wire and the refractive index determined. From this measurement the composition of the plagioclase can be found from the graph given by Foster (1955, Fig. 1).

The limitation of the method depends on the worker's capability to handle small pieces of material. Modifications will be readily apparent to anyone contemplating setting up the apparatus. We now derive our power supply by passing the mains current through a transformer-rectifier, while the platinum wire itself can be removed from its insulated holder.

I should like to express my thanks to Dr. J. P. Webb and Mr. P. S. Upton for their assistance in setting up the apparatus.

REFERENCE

- FOSTER, W. R. (1955) "Simple method for the determination of the plagioclase feldspars." *Am. Mineral.*, **40**, 179-185.

THE AMERICAN MINERALOGIST, VOL. 43, MARCH-APRIL, 1958

A DOUBLE ARC GONIOMETER HEAD FOR CRYSTAL ORIENTATION, SAWING AND GRINDING*

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INTRODUCTION

Although the double arc goniometer head is a well known crystallographic instrument, units which possess not only adequate versatility for optical and x-ray diffraction orientation work but also sufficient strength to serve as sawing and grinding mounts are uncommon. Descriptions of previous instruments having these features to some degree have been given by A. E. H. Tutton (1), F. E. Wright (2) and M. J. Buerger and J. S. Lukesh (3). It is believed, however, that the goniometer

* Contribution from the Department of Mineralogy, University of Michigan, No. 212. This work has been supported financially by the Office of Naval Research and the Army Signal Corps, Fort Monmouth, N. J.

head described in this paper offers some improvements with respect to versatility, ruggedness, and accuracy, especially for the preparation of oriented specimens from large crystals of relatively hard materials. Because the instrument is designed primarily for relatively large boule type crystals, the translation motions usually employed on goniometer heads have been omitted.

The instrument has been in satisfactory operation for a period of approximately two years. A total of about 40 oriented prisms of various shapes have been accurately prepared (tolerance = 15 minutes of arc or less) from materials such as boules of silicon, strontium titanate and synthetic ruby, and crystals of quartz, periclase and microcline.

GONIOMETER HEAD DESCRIPTION

The overall height of the unit and its greatest width are each approximately $2\frac{1}{2}$ inches. Steel is used for all components. All straight surfaces are either milled or ground flat and parallel. Moving and guide arcs are lathe machined from cold rolled round stock. All fixed parts of the instrument are secured with steel flathead screws. Steel to steel friction clamp mechanisms or set screws are provided for locking all moving parts.

The goniometer head consists of the following basic parts: (1) a solid rectangular top section, $1\frac{1}{8} \times \frac{7}{8} \times \frac{7}{8}$ inches, which carries one set of arcs and contains a $\frac{3}{8}$ inch diameter vertical central shaft opening to receive detachable specimen holders of various designs. The latter may be secured at any desirable position by means of a set screw lock. Sealing wax, Plaster of Paris, solder and various quick drying organic cements have been successfully used for mounting crystals in specimen holders; (2) a center section of rectangular U-shaped cross section which carries a set of guide arcs parallel to those of the top section and a second set oriented at right angles to those of the top section. The dimensions of the side plates of the center section are $1\frac{9}{16} \times 1\frac{1}{8} \times \frac{1}{8}$ inches and those of the base plate $1\frac{1}{8} \times 1\frac{1}{8} \times \frac{3}{8}$ inches; (3) a base section, also of U-shaped cross section, carrying a set of guide arcs to receive those of the center section and having a $\frac{3}{8}$ inch diameter central shaft opening in the base plate coaxial with the hole of the top section. The base hole is used for mounting the assembled goniometer head on orienting, sawing or grinding equipment and also permits a 360° rotation of the head about the mounting axis. An allen head set screw is provided for locking the goniometer head to a shouldered spindle. The dimensions of the side plates of the base section are $1\frac{1}{16} \times 1\frac{1}{2} \times \frac{1}{8}$ inches, and those of the base plate are $1\frac{1}{16} \times 1\frac{3}{8} \times \frac{3}{8}$ inches.

Both sets of arcs are designed for a 45° traverse about a common

center $\frac{7}{8}$ inch above the top surface of the top section. The width of all arcs is $\frac{1}{8}$ inch. Both sets of arcs are manipulated by rack and pinion drives.† The racks, standard 48 pitch $\frac{1}{8} \times \frac{1}{8}$ inch stock, are attached to the underside of the top and center sections of the instrument with steel flathead screws. The undersides of the sections are filed to the proper curvatures with respect to the common center point and the racks are bent to this same curvature. The pinion shafts, $\frac{3}{16}$ inch diameter 48 pitch pinion wire, are provided with fixed turning knobs at one end and threaded locking knobs at the other. This type of assembly permits the vertical sides of the center and base sections to be clamped against the sides of the top and center sections, respectively, thereby providing an effective locking action on arc movement. An operating clearance of approximately 0.0005 inch is provided between the vertical sides of the respective sections. Clearance adjustment may be made by placing shims under the arcs. All components of the goniometer head have been nickel plated to prevent rust.

Calibration of arc movement may be carried out optically by attaching a mirror to the specimen mount and reflecting a collimated point source of light upon a calibrated screen. The pinion knobs may then be divided to read in degrees of arc rotation about the common center point.

Some backlash is inherent in the gearing mechanism due to the necessity of bending the racks to their respective curvatures. However, with proper calibration and care in operation, the system operates well and has the advantage of being both cheap and easy to construct. The construction cost of the goniometer head is approximately \$200.

Fig. 1 provides a view of the assembled goniometer head with a specimen holder. Included in the photograph is a typical crystal boule and some oriented cut specimens.

Fig. 2 shows the goniometer head mounted on a Laue back reflection x-ray camera. Most orientation work on boule crystals must be carried out by x-ray diffraction since they generally lack crystallographic surfaces suitable for optical orientation. Fig. 2 provides a more detailed view of the rack and pinion gearing and also shows the adapter coupling used for mounting the goniometer head on a standard two circle optical goniometer (see lower left of photograph).

The technique used to orient crystals by back reflection x-ray diffraction consists of photographing diffraction patterns on 3×4 inch sections of Kodak no-screen x-ray safety film with an intensifying screen backing used in the film holder. A special punch is used to produce a precision hole at the center of the film in order to insure accurate and reproducible positioning of the film around the x-ray collimating tube. A

† Rack and pinion stock was obtained from the Chas A. Strelinger Co., Detroit, Mich.

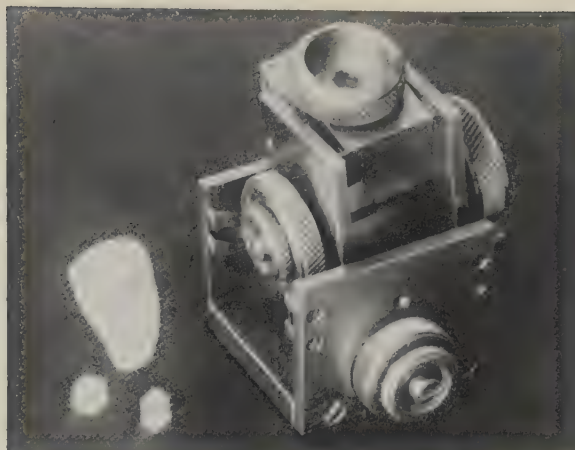


FIG. 1. A view of the double arc goniometer head. Included in the photograph is a typical crystal boule and some oriented cut specimens.

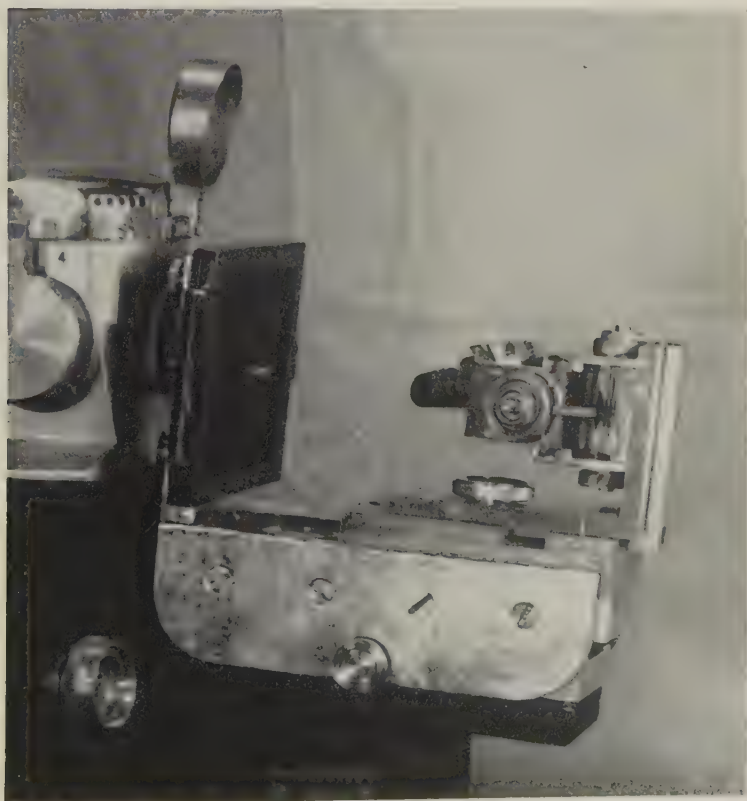


FIG. 2. A view of the goniometer head mounted on a Laue back reflection camera.

fiducial pinhole was cut into one corner of the opaque paper front of the film holder to insure correct correlation between diffraction pattern photographs and crystal orientation.

A copper target x -ray tube operated at 30 KV and 15 MA produces a satisfactory diffraction pattern with a 10 to 15 minute exposure. A collimating aperture of $\frac{1}{32}$ inch was used. Orientation of single crystals to within 15 minutes of arc usually can be accomplished with five or six exposures. The first one or two patterns establishes the orientation of the crystal with respect to the x -ray beam. Another one or two are required to bring the specimen to within 1° of the desired orientation, and a final one or two to reduce the error to less than 15 minutes.

If the specimen possesses features such as crystal or cleavage faces, preliminary orientation frequently can be made by crystallographic inspection with light reflected from these surfaces. When such pre-orientation is possible, final orientation by x -ray diffraction can usually be done with two or three exposures.

Goniometer adjustments are determined by placing films over a calibrated net. The latter consists of a section of plate glass showing a series of concentric circles centered on a combination orthogonal and hexagonal axial system. The increase in radius for each successive circle is equivalent to a given number of degrees of arc for a given crystal to film distance. Illumination of the net is from behind. For all films except that of the final orientation, only a short fix and quick water rinse are required prior to inspecting the photographed diffraction pattern.

After the orientation of a crystal specimen is completed and the arcs are locked, the goniometer head, with specimen undisturbed, may be transferred directly to a diamond cut-off saw or grinding equipment. An angle plate type of mount for the goniometer head as shown on the back reflection camera of Fig. 2 also serves as an excellent sawing or grinding mount, especially since the principal axis can be mounted either horizontally or vertically. Saws and grinders equipped with accurate rotary work tables permit several oriented cuts to be made with a single orientation of the crystal. For equipment requiring a spindle type of mounting, for example, the grinding apparatus described by R. M. Denning (4), the goniometer head may be directly fastened through the central shaft opening in the base plate.

The writer gratefully acknowledges the assistance received from Prof. R. M. Denning in designing the goniometer head and for critically reading the manuscript.

REFERENCES

1. TUTTON, A. E. H., *Crystallography and Practical Crystal Measurement*, Vol. II, p. 932, Macmillan & Co. (1922).
2. WRIGHT, F. E., *J. Wash. Acad. Sci.*, **5**, 35 (1915).
3. BUERGER, M. J., AND LUKESH, J. S., *Am. Mineral.*, **21**, 667 (1936).
4. DENNING, R. M., *Am. Mineral.*, **38**, p. 108 (1953).

PRESIDENT'S AWARD FOR DISTINGUISHED CIVILIAN SERVICE

In ceremonies at the White House on January 27, 1958, Dr. Sterling B. Hendricks was one of five recipients of the first President's Award for Distinguished Civilian Service. The following citation was read: "His discoveries in soil clays, phosphate minerals, radioisotopes, plant physiology and fundamental chemistry make him one of the most distinguished and honored scientists of our time."

Dr. Hendricks is Chief Chemist, Mineral Nutrition Laboratory, Soil and Water Conservation, Beltsville, Md. He has been a Fellow of the Mineralogical Society of America since 1940, and served as its President in 1954.

BOOK REVIEWS

IRON ORE BENEFICIATION, by LAWRENCE A. ROE. ix+305 pages, Minerals Publishing Company Lake Bluff Illinois 1957. Price \$5.00.

This book is a discussion of the iron ore minerals and of the techniques and equipment peculiar to iron ore beneficiation. It is assumed that the reader will be familiar with subjects common to the general field of minerals beneficiation, such as crushing, grinding, and sizing.

There are many handbooks and textbooks covering the general field of minerals beneficiation, but very few have attempted to put together the details for specialized branches such as beneficiation of the ores of a single element.

The volume under review has as its principal object the gathering in one place of the many scattered bits of information relating to iron ore beneficiation, but it is in no sense a handbook or textbook. Its broad coverage, as well as the numerous footnote references and lengthy lists of additional references at the end of each chapter, should make the book very useful to the increasing numbers of minerals beneficiation engineers who are primarily concerned with the processing of iron ore minerals, as well as to those in related fields who would like a general and readable summary of the subject.

The volume is a clearly reproduced and easily readable offset printing from type-script. There are more typographical errors than would be expected from this method. It is a little surprising to find the lists of additional references arranged neither alphabetically nor chronologically.

With the increasing importance that the taconites are assuming in the domestic production of iron ore minerals it is logical that the three longest chapters in a work of this kind, other than the one on descriptions of the minerals themselves, should be those on techniques involved in processing these ores—Pyrometallurgical Processing, Magnetic Separation and Agglomeration.

The concluding chapter on Research is unexpectedly short—a little over three pages of text and four pages of Additional References. It is more a concentrated outline of the history of such research and its cost rather than an attempt to assess current research and to point out future needs and possible trends.

The Index is also quite inadequate, attempting to cover 300 pages of text with only five lightly filled pages of index.

EARL INGERSON

TABLES PERMETTANT LE DÉPOUILLEMENT DES DIAGRAMMES DE RAYONS X ET ABQUES DE RÉGLAGE DES MONOCHROMATEURS À LAME COURBE, by A. J. Rose, 141 pages, 21×27 cm. Centre National de la Recherche Scientifique (C.N.R.S.), 13 Quai Anatole-France, Paris 7^e, 1957. Price (bound): \$4.50.

The author is both a mineralogist at the Sorbonne and a research director at the C.N.R.S. He is famous for the x-ray photographs he takes. Whoever has seen his exhibit at the Montreal Congress will tell you he is a perfectionist.

The main table (Table I) gives the function $\lambda/2 \sin x$ to 5 significant figures for six different wavelengths¹ ($K\alpha_1$ of Cu, Ni, Co, Fe, Cr, and Mo) and for all values of x in steps of 0.01° from 0.01° to 89.99° . In view of the analogy between the two formulae

$$a_{uvw}/2n = \lambda/2 \sin \phi_n \quad \text{and} \quad d_{hkl} = \lambda/2 \sin \theta,$$

the table can be used to obtain the period a_{uvw} of the rotation axis $[uvw]$ from a rotating-crystal pattern ($x = \phi_n$) or the interplanar distance d_{hkl} from a powder pattern ($x = \theta$). It

¹ Erratum: p. 7, line 1, instead of $K\alpha$ read $K\alpha_1$.

is not necessary, however, to calculate the value of x , as two additional columns list the quantities²

$$\delta = 2R \tan \phi_n \quad \text{and} \quad \Delta = 4R\theta,$$

each for two camera radii, $R = 180/2\pi$ and $R = 240/2\pi$ mm. These arguments are simple functions of the measured distance between two symmetrical lines on the film; in the case of the usual rotation pattern, $\delta = 2h_n$ is the distance between the two n^{th} -layer lines; in the Mauguin rotation method (film perpendicular to rotation axis), $\delta = 2RH/h_n'$, where H is the crystal-to-film distance and h_n' the radius of the (circular) layer line; in the Debye-Scherrer powder pattern $\Delta = 2l$ or $2\pi R - 2l$, according as $2l$ is the distance between two corresponding forward-reflection lines or back-reflection lines; in the Seeman-Bohlin patterns, $\Delta = l$ (transmission) or $2\pi R - l$ (back reflection). For a camera with radius $2R$, use $\Delta = l$ instead of $\Delta = 2l$.

The numerical values of the wavelengths are those of Cauchois and Hulubei, multiplied by 1.00202 so as to be expressed in Å units. They differ, only in the fifth place, from the ones commonly used (*Acta Cryst.* 1, p. 46, 1948). Table IIa gives atomic weights and mass absorption coefficients for the $K\alpha$ of Mo, Zn, Cu, Ni, Co, Fe, Mn, and Cr. Table IIb lists $e^{-\mu}$ to 4 decimals for $x = 0(0.01)5.50$ and $5.50(0.10)9.90$.

Curved quartz crystal monochromators of two types (Johann, 1931; Johansson, 1933) are used almost routinely in French laboratories. This fact explains why Table I refers to $K\alpha_1$ wavelengths only; it also accounts for the nomographs included in the volume. Let the quartz plate of such a monochromator be cut at an angle σ to the reflecting planes (10 $\bar{1}$ 1), let r be the radius of curvature of the net planes (10 $\bar{1}$ 1), SC the distance from the x-ray source S to the plate center C, and CF the distance from C to the focalisation line F. Each nomograph corresponds to a certain wavelength ($K\alpha$ of Mo, Cu, Ni, Co, and Fe) and gives SC and CF (mm.) in terms of r (mm.) for several values of σ . The nomographs solve two problems: (1) Find the focal distances SC and CF of an available monochromator used with a given x-ray wavelength. (2) Select a monochromator that possesses desirable values of SC and CF, imposed, say, by space available.

The presentation is clear. The tables were first printed by I.B.M. machines, then reproduced by photo offset with a 2 to 1 reduction, which does not impair their legibility.

DONNAY AND DONNAY

REFERENCES

- JOHANN, H. H. (1931), *Z. Phys.*, **69**, 185.
JOHANSSON, T. (1933), *Z. Phys.*, **12**, 507.

² *Erratum*: in column 3, instead of $4r\theta$ read $4R\theta$.

NEW MINERAL NAMES

Iron-alabandite

PAUL RAMDOHR. Eisenalabandin, ein merkwürdiger natürlicher Hochtemperaturmischkristall. *Neues Jahrb. Mineral., Abhandl. (Festband Hans Schneiderhöhn)* **91**, 89-93 (1957).

The mineral is cubic, with perfect cubic cleavage, and has the halite structure with $a_0 = 5.15$ Å. It appears to be a solid solution, (Mn, Fe)S, with Mn slightly predominant over Fe. It resembles tetrahedrite in polished section, but is harder. It was found in pyrrhotite in the wollastonite-bearing phonolite quarry at Fohberg near Oberschaffhausen, Kaiserstuhl, Germany. Chalcopyrite and a little sphalerite were associated minerals. It was also found with pyrrhotite in the native iron from the basalt at Bühl, Germany. The composition is close to the limit of solubility of FeS in MnS.

MICHAEL FLEISCHER

Sborgite

CURZIO CIPRIANI. *Un nuovo minerale fra i prodotti boriferi di Larderello. Atti accad. nazl. Lincei, Rend. classe sci. fis., mat. e nat.* **22**, 519-525 (1957).

Two analyses are given of incrustations formed in 1930 and in 1948 at the well-known soffioni in Tuscany. They contain mainly Na_2SO_4 plus sodium borates, but the ratios $\text{Na}_2\text{O} : \text{B}_2\text{O}_3$ (after deducting Na_2SO_4) were 1:3.17 and 1:3.81, indicating the presence of a borate other than borax. X-ray powder data of the mixture, after deducting the lines of thenardite and borax, agreed with the pattern of the well-known synthetic compound $\text{NaB}_3\text{O}_8 \cdot 5\text{H}_2\text{O}$.

Synthetic crystals had G_c 1.713 and were optically biaxial, positive, with α 1.431, β 1.438, $2V$ 35° , γ 1.507 (calcd.). Grains isolated from the crusts had α' 1.435, γ' 1.450-1.460. Unindexed x-ray powder data are given for the synthetic compound; the strongest lines are 4.60 (100), 3.30 (77), 3.20 (76), 2.572 (39), 3.56 (38), 3.54 (36), 6.88 (36).

Solubility data on the compound and on thenardite indicate that the temperature of formation was between 32° and 60° .

The name is for Umberto Sborgi (1883-1955), Italian chemist, who published solubility data on the system $\text{Na}_2\text{O}-\text{B}_2\text{O}_3-\text{H}_2\text{O}$.

M. F.

Uranium minerals from U.S.S.R.

Two Russian monographs on uranium minerals have become available recently: M. V. SOBOLEVA and I. A. PUDOVKINA (S. and P.), *Mineraly Urana, Spravochnik (Uranium Minerals Handbook)*, Moscow, 1957, 404 pp., and R. V. GETSEVA and K. T. SAVEL'eva (G. and S.), *Rukovodstvo po opredeleniiu uranovykh mineralov (Handbook for the determination of uranium minerals)*, Moscow, 1956, 260 pp. The following information is from these books; most of the minerals were listed without any information except formula in *Am. Mineral.* **41**, 816 (1956), **42**, 307 (1957).

It is worthy of note that no locality names are given in either book. Nor are any references given to the original descriptions.

Ufertite

S. and P., p. 350-352, G. and S., p. 132.

Analyses by P. N. Dorofeev gave TiO_2 59.12, 50.00; FeO 14.0, —; Fe_2O_3 11.00, 32.96; Cr_2O_3 1.2, 0.8; Al_2O_3 0.2, —; rare earths 11.58, n.d.; ThO_2 0.16, 0.20; UO_2 2.61, —; PbO 0.20, 0.21; V_2O_5 0.37, —; SiO_2 1.2, 0.3; sum 101.64%, —. A semiquantitative spectral analysis gave also Zn 0.8, Zr 0.05-0.1, Nb, Ta none, Mn 0.8, Cu 1.0, K 1.0, La 2.5, Ce 3.5, Y 1.3, and less Pr, Nd, Gd, Dy.

The formula deduced is $20\text{FeO} \cdot 8\text{Fe}_2\text{O}_3 \cdot 4\text{TR}_2\text{O}_3 \cdot \text{UO}_2 \cdot 74\text{TiO}_2$. The mineral is slightly soluble in H_2SO_4 . Fusible with KOH or KHSO_4 . The DTA curve shows a broad endothermic effect near 200° and an exothermic effect at 530 – 670° .

Color black with brownish tint, luster resinous. G. 4.33 (pycnometer), hardness 6.6–7.2. Non-magnetic. Fracture conchoidal. Optically isotropic, translucent only in fine splinters, n (melts) 2.11, but 2.16 after being heated at 800° . Reflecting power 19–21, somewhat less in altered material.

An unindexed x-ray pattern is given of material heated at 700° . The strongest lines are 1.452 (10), 1.616 (9), 2.892 (7), 2.772 (from the position in the table, perhaps this should be 2.272 M. F.) (6), 1.821 (6).

Uferrite is known from one locality where it occurs in irregular masses and elongated crystals in biotite-gneisses and quartz-biotite schists, cut by veins of albite. It is associated with albite, sericite, calcite, hematite, and sulfides. Discovered by N. I. Balashov (S. and P.), by P. V. Veinerman and N. P. Balazhev in 1950 (G. and S.).

DISCUSSION.—This appears to be a variety of davidite. The x-ray pattern is close to, but differs slightly from the variable patterns given by others for davidite.

M. F.

Irriginite

S. and P., p. 249–251; G. and S., p. 197.

Chemical analysis by V. A. Iskuyil, 1951, gave MoO_3 38.62, UO_3 41.91, UO_2 none, CaO 0.46, loss on ignition 9.7, insol. 9.04, sum 99.73%, corresponding to $\text{UO}_3 \cdot 2\text{MoO}_3 \cdot 4\text{H}_2\text{O}$. The formula is given by G. and S. as $\text{U}_2^{+6}(\text{MoO}_4)(\text{OH})_4 \cdot 4\text{H}_2\text{O}$.

The mineral occurs as very fine-grained dense yellow aggregates, sometimes forming pseudomorphs after brannerite. Luster dull. Hardness 4–5. G. 3.84. Fracture conchoidal to uneven. Indices of refraction, α 1.82, γ 1.93, birefringence very high. Gives a sharp x-ray pattern (57 lines are given) with strongest lines 3.222 (10), 1.129 (8), 2.625 (6), 2.142 (6), 1.836 (6), 1.249 (6), 1.206 (6), 1.188 (6), 1.165 (6), 6.390 (5), 1.693 (5), 1.533 (5). It is monoclinic according to G. and S.

The mineral was found by G. Yu. Epshtein in 1951, studied by Yu. V. Kazitsyn in 1954. It occurs in one deposit in granulated albitite, associated with brannerite and with other U-Mo minerals. One of the latter occurs in yellow-green radial aggregates, weakly pleochroic, α 1.775, birefringence high, extinction parallel, H. 1–2.

M. F.

Lermontovite

S. and P., p. 181–182; G. and S., p. 199–200.

Analysis by A. Ya. Sheskolskaya, 1952, gave P_2O_5 20.40, UO_3 14.53, UO_2 36.53, CaO 1.00, R_2O_3 (apparently rare earth oxides M. F.) 1.67, SiO_2 2.38, F none, sum 85.03%. The sample contained admixed molybdenum sulfate. G. and S. give the same analysis and also Te_2O (Ti_2O ? M. F.) 1.55, sum 86.61% (adds to 86.58 M. F.).

Assuming quadrivalent uranium, the formula is given as $(\text{U}, \text{Ca}, \text{TR})_3(\text{PO}_4)_4 \cdot 6\text{H}_2\text{O}$.

The mineral occurs in botryoidal aggregates of radial fibrous needles. Color grayish-green, luster dull, silky in fractures. G. 4.50. Very brittle. Under the microscope transparent grassy-green, pleochroic in greenish and greenish-brown hues. Extinction parallel. Indices of refraction variable, even in a single sample, α 1.562–1.574, γ 1.702–1.726 (S. and P.), α 1.562–1.702, γ 1.574–1.726 (G. and S.). No x-ray data are given.

Occurs under sharply reducing conditions in the zone of cementation of hydrothermal deposits, associated with molybdenum sulfate, marcasite, hydrous silicates, and “thallium ocher.”

The mineral was first described by V. G. Melkov in 1952.

DISCUSSION.—Needs further study.

M. F.

Lodochnikite

S. and P., p. 347–350; G. and S., p. 131–132.

Analysis by A. P. Bocherov, 1948, gave TiO_2 42.05, UO_3 35.41, UO_2 16.45, ThO_2 3.96, $(\text{Nb}, \text{Ta})_2\text{O}_5$ 0.14, CaO none, MgO 0.68, PbO 0.13, Fe_2O_3 0.25, Al_2O_3 0.12, SiO_2 0.21, H_2O 0.04, loss on ignition 0.55, CO_2 0.12 (G. and S. give S 0.12 instead), sum 100.11%, corresponding to $2(\text{U}, \text{Th})\text{O}_2 \cdot 3\text{UO}_3 \cdot 14\text{TiO}_2$. Difficulty soluble in HCl and HNO_3 , slightly soluble in H_2SO_4 , readily fusible with KHSO_4 .

The mineral is black, with strong resinous luster. Opaque except in thin splinters. Streak black, slightly brownish. n (melts) = 2.16, after being heated, $n = 2.19$. Reflecting power 19%. Fracture conchoidal. Hardness 5–6. G. (pycnometric) 5.48, after being heated at 800° the mineral has G. 5.55. (The table of analytical data gives G. 5.88 M. F.) A DTA curve gave a sharp exothermal effect at 620 – 650° , and weak endothermal effects at about 700° and 860° .

X-ray powder data are given for material heated one hour at 900 – 1000° . The strongest lines are 2.017 (7), 1.979 (7), 1.650 (7), 2.419 (6), 3.079 (5), 1.749 (5); 34 others are given.

Lodochnikite was discovered by Ya. D. Gotman in 1948 as veinlets in nepheline-microcline-muscovite rock, the veins also containing barite, siderite, hematite, and calcite.

The name is for the Soviet petrographer V. N. Lodochnikov.

DISCUSSION.—The editors of Soboleva and Pudovkina remark that “separation of lodochnikite as an independent mineral is of uncertain expediency. It might be considered as a variety of brannerite with increased content of uranium.” I agree. The x-ray powder pattern resembles that of heated brannerite, but there are considerable differences in the intensities.

M. F.

Moluranite

S. and P., p. 252–253; G. and S., p. 196.

Analysis by V. A. Iskuy, 1951, gave MoO_3 37.5, U_3O_8 42.32, SiO_2 4.56, H_2O 15.4, sum 99.78% (U^4 and U^6 not determined), according to S. and P.; MoO_3 38.50, UO_3 42.32, SiO_2 4.56, loss on ignition 14.03, sum 99.41%, according to G. and S. Formula $\text{UO}_2 \cdot 2\text{UO}_3 \cdot 5\text{MoO}_3 \cdot 12\text{H}_2\text{O}$ (?) (S. and P.), $2\text{UO}_2 \cdot 3\text{MoO}_3 \cdot 11\text{H}_2\text{O}$ (?) (G. and S.). When heated to 500° , gives off water, turns yellow, and is transformed into iriginite. “Dissolves very poorly in acids.”

Color black, translucent brown in thin fragments. Luster resinous. Hardness 3–4, brittle. Isotropic, n 1.97–1.98 (G. and S.), “approximately 1.79–1.98” (S. and P.) (misprint?). Under x-ray study, it is stated that the mineral has no crystal structure (G. and S.).

Occurs in fine fissures in granulated albitite, associated with molybdenite, chalcopyrite, and galena, which are incrustated on fissures, moluranite forming colloform accumulations in the central part with brannerite and with other U-Mo compounds. Known from one deposit.

The name is from the composition.

M. F.

Obruchevite

G. and S., 1956, p. 140.

Found by Nefedov in 1941 and referred to ellsworthite. Analysis gave N_2O (presumably Na_2O) 4.42, K_2O 0.48, CaO 2.86, FeO 3.85, SiO_2 1.78, UO_2 5.98, Ce_2O_3 0.13, Y_2O_3

19.14, TiO_2 0.40, ThO_2 0.80, Ta_2O_5 10.25, Nb_2O_5 (should be $\text{Nb}_2\text{O}_5?$) 10.06, H_2O 8.90, sum 69.05%. (The sum is given as 99.04; presumably either Ta_2O_5 should be 40.25 or Nb_2O_5 40.06% M. F.) The formula is given as $3\text{Na}_2\text{O} \cdot 4(\text{Ca}, \text{Fe})\text{O} \cdot 3\text{Y}_2\text{O}_3 \cdot (\text{U}, \text{Th})\text{O}_2 \cdot 5(\text{Ta}, \text{Nb})_2\text{O}_6 \cdot 20\text{H}_2\text{O}$.

Forms dense masses without crystal form. Isotropic. Metamict, gives a cubic pattern after being heated. Color light brown, luster greasy to adamantine. Fracture conchoidal. G. 3.96–4.80.

A rare mineral, found in granitic pegmatites, associated with allanite, garnet, feldspar, and unstudied niobates.

DISCUSSION.—This is evidently a variety of the pyrochlore-microlite group, which has the highest yttrium content yet found in this group.

M. F.

Orlite

S. and P., pp. 129–130; G. and S., p. 239.

Analysis by L. A. Kuznetsova, 1952, gave SiO_2 12.08, UO_3 43.57, P_2O_5 0.65, As_2O_5 0.25, PbO 32.45, CaO 0.76, BeO 0.22, MgO 0.84, Al_2O_3 2.54, Fe_2O_3 0.80 H_2O^- 2.97, H_2O^+ 2.25, insol. 1.44, sum 100.82%. Of the H_2O^+ , 1.11% is lost at 200° , 0.85% to 300° , 0.29% to 1000° . The formula is given as $3\text{PbO} \cdot 3\text{UO}_3 \cdot 4\text{SiO}_2 \cdot 6\text{H}_2\text{O}$. The mineral is soluble in HCl with separation of PbCl_2 and gelatinous silica.

The mineral is in radiating aggregates of fine acicular crystallites, measuring tenths of a mm. Color light creamy yellow, luster waxy. G. 5.307. Non-luminescent in ultra-violet light. Crystal system and optical character not determined. Extinction parallel, elongation negative, $n_s \gamma$ 1.793, β 1.788. The x -ray powder pattern (34 lines) has the strongest lines 3.226 (10), 1.678 (7), 6.356 (5), 1.967 (5), 1.849 (5).

Orlite is known from one locality where it is associated with uranophane and kasolite in the middle horizon of the oxidation zone of uranium deposits in liparite. It was found by V. G. Melkov and A. M. Sergeev in 1951.

The name is for the locality.

DISCUSSION.—Needs further study. Orlite corresponds very closely in composition and physical properties to kasolite, $\text{PbO} \cdot \text{UO}_3 \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$. The x -ray pattern given for orlite is very close to that given for kasolite by Frondel, Riska, and Frondel, *U. S. Geol. Survey Bull.* **1036-G** (1956), but differs from that given for kasolite by S. and P. The n_s given for orlite are very different from those of kasolite.

M. F.

Przhevalskite

S. and P., p. 203–205; G. and S., p. 213.

Analysis by A. Ya. Sheskol'skaya, 1947, gave P_2O_5 11.47, UO_3 46.55, PbO 21.06, H_2O 6.69, Al_2O_3 3.48, and SiO_2 4.10, sum 93.35%. (G. and S. omit the Al_2O_3 , add "insol. 1.99%" and give also PbO 21.66, but their sum is 0.6% too high.) This gives after deducting meta-halloysite, the formula $\text{Pb}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$. The mineral has been synthesized at pH 4.2. It is readily soluble in acids.

Orthorhombic. G. and S. state that synthetic przhevalskite has the crystal structure of torbernite. The mineral occurs in foliated aggregates of tabular crystals, ranging in size from 0.1 to 1 mm. Cleavage (001), "clearly expressed." Color bright yellow with a faint greenish tint. Luster adamantine, pearly (S. and P.), strong, vitreous (G. and S.). G. and hardness not given. Optically biaxial, negative, with $n_s \alpha$ 1.739, β 1.749 ± 0.002 , γ 1.752 ± 0.002 , $\gamma - \alpha$ 0.013–0.014, $2V$ about 30° (S. and P.); α 1.739, β 1.749 – 1.750 , γ 1.752 – 1.753 , $2V$ medium (G. and S.). Extinction parallel, elongation negative. Pleochroic with X colorless, Y pale yellow, Z deep yellow.

Przhevalskite gives a sharp x -ray pattern; 55 lines are listed. The strongest are 3.610 (10), 9.080 (9), 1.619 (6), 1.530 (6), 9.490 (5), 2.629 (5), 1.960 (5), 1.349 (5), 1.148 (5), 1.138 (5).

The mineral is rare, occurring in the oxidation zone of a pitchblende-sulfide deposit with torbernite, autunite, dumontite, renardite, uranophane, metahalloysite, hydrous oxides of iron and manganese, and wulfenite.

The mineral was first described by V. G. Kruglov in 1946. It was named for N. M. Przhevalsk.

DISCUSSION.—The x -ray pattern differs from those of the other lead uranium phosphates, and the optical data differ from all of these except renardite. The x ray pattern has some resemblance to those of members of the metatorbernite group.

M. F.

Sogrenite

S. and P., p. 257–259; G. and S., p. 250–251.

An organo-uranium complex. Two analyses gave C 18.27, 20.46; H 2.40, 2.32; S not detd., 1.18, ash 59.27, 59.26%. Microchemical analyses of the inorganic part by L. A. Kuznetsova, 1949, gave CaO 7.57, 8.16; MnO 0.09, 0.07, MgO 0.89, 0.30; PbO 0.48, 0.19; Al_2O_3 12.70, 4.59; Fe_2O_3 13.48, 2.98; UO_3 11.80, 19.99; SO_3 3.42,—; S—, 1.96; SiO_2 4.01, 1.72; ThO_2 none, none; P_2O_5 6.27, 13.88; As_2O_5 none, not detd.; V_2O_5 none, not detd.; H_2O^- 6.04,—; H_2O^+ 10.82, 16.70 (total H_2O), ignition loss 19.93, 28.75, sum 97.50, 99.29 (given as 98.75%). Dry distillation gave gases and water 20.8, coke 49.2%, tar none.

Color black, luster strongly resinous, streak brownish-gray, brownish-black. Brittle, fracture conchoidal. Hardness (Vickers) $335 \text{ kg./mm.}^2 = 4.9$. G. (pycnometer) 2.0–2.2. Poorly wet by water. Opaque. Isotropic. The x -ray pattern, after heating at 850° , is that of a cubic mineral with strongest lines at 3.028 (8), 2.125 (7), 1.854 (7), 2.802 (6), 1.302 (6).

In the air tarnishes, cracks, and turns to a brown friable mass. If then moistened, it swells and again shows a strong luster.

Sogrenite was discovered by E. A. Nachaev and A. A. Arsen'ev in 1949. It occurs in ankerite-calcite veins cutting Proterozoic limestones and is associated with chlorite, chalcidony, pyrite, sphalerite, and galena.

DISCUSSION.—The editor of the monograph by S. and P. remarks, "Sogrenite, like thucholite and carburan, is not a mineral, but is referred to the series of organic materials adsorbing different inorganic materials."

M.F.

Ferutite

G. and S., pp. 126–128.

A note on this name was printed in *Am. Mineral.* 41, 163–164 (1956); the name applies to the davidite-like mineral from Mozambique described by Bannister and Horne, *Mineralog. Mag.* 29, 101–112 (1950). It is not clear from the data given which measurements are on Mozambique, which on Russian material.

Analysis gave TiO_2 59.11, UO_2 6.19, UO_3 5.24, $FeO + Fe_2O_3$ 26.00, PbO 3.46, Ce_2O_3 trace, sum 100.00% (recalculated? M. F.). Black with resinous to semi-metallic luster, translucent brown to reddish-brown in thin splinters. Fracture conchoidal. Hardness 5.7–6.1 (absolute microhardness 544–667 kg./mm.^2). G. 4.46. Isotropic, metamict.

Two x -ray patterns are given of material heated at 1000° ; these differ considerably in intensities. The strongest lines of one are 1.687 (10), 2.480 (7), 3.246 (6), 2.885 (6), 2.242 (5), 1.797 (5), 1.124 (5), 1.088 (5).

Ferutite was found in sands containing magnetite, rutile, zircon, apatite, and tourmaline.

The name is for the composition.

DISCUSSION.—Not certainly distinct from davidite.

M. F.

Unnamed Phosphate Analogue of Walpurgite

S. and P., p. 201–202.

Qualitative tests showed the presence of Bi, U, PO_4 , and H_2O , with traces of Na and K. Decomposed by nitric acid. The mineral is yellow, with vitreous luster, hardness high, brittle. Found as stellate aggregates, up to 1 mm. Extinction nearly parallel, elongation positive, n_1 1.722 ± 0.002 , n_2 1.783.

The mineral was first described by V. G. Melkov in 1946. It occurs in the near-surface part of the zone of oxidation.

M. F.

Sodium Autunite

A. A. CHERNIKOV, O. V. KRUTETSKAYA, AND N. I. ORGANOV. Sodium-autunite *Atomnaya Energiya*, **3**, 135–140 (1957) (in Russian).

Analyses of 2 samples by O. V. K. and V. I. Litenskov gave UO_3 61.9, 62.53; P_2O_5 15.56, 14.69; Na_2O 5.62, 6.88; CaO 1.2, 0.14; MgO 0.43,—; SiO_2 1.6,—; CO_2 0.24,—; Al_2O_3 0.32,—; Fe_2O_3 0.97,—; H_2O^- 9.02,—; H_2O^+ 4.05, 14.84 (total H_2O), sum 100.91, 99.08%. These give the ratios $\text{UO}_3:\text{P}_2\text{O}_5:\text{Na}_2\text{O}+\text{CaO}:\text{H}_2\text{O}=1.91:1.00:1.02:6.66$ and $2.1:1.0:1.06:7.9$. The mineral is readily soluble in acids. Gives off water in the closed tube, turning straw-yellow and porous.

The mineral occurs in lemon-yellow and lettuce-yellow plates with perfect cleavage on (001) and a less perfect one on (100). Sometimes in foliated and radiating masses. Brittle, hardness $2-2\frac{1}{2}$. G. 3.584, calcd. for $8\text{H}_2\text{O}$ 3.89. Luster pearly on (001), vitreous on other faces. Luminesces strongly in yellow-green under ultra-violet light. Fresh crystals are uniaxial, neg., with ns ω 1.578, ϵ 1.559, pleochroism weak, O light yellow, E pale yellow. After two days exposure at $35-40^\circ$, the ns were ω 1.585, ϵ 1.564.

X-ray study showed the mineral to be tetragonal, $P4/nmm$, with a 6.97, c 8.69A., $c/a=1.245$; the unit cell contains $\text{Na}_2(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$. Data are also given for synthetic calcium- and H-autunites. Indexed x-ray powder data are given; the strongest lines are 3.67 (10), 2.675 (8), 1.566, 1.540 (8, broad), 3.23 (7), 1.639 (7), 1.364 (7).

The mineral occurs "in one of the granodiorite massifs of the U.S.S.R." A member of the meta-autunite group, well known as a synthetic compound (Fairchild, *Am. Mineral.* **14**, 7–8 (1929)).

M. F.

Sodium uranospinite

E. V. KOPCHENOVA AND K. V. SKVORTSOVA. Sodium uranospinite. *Doklady Akad. Nauk S.S.S.R.*, **114**, 634–636 (1957) (in Russian).

Microchemical analysis gave UO_3 58.29, P_2O_5 1.65, As_2O_5 20.84, CaO 1.87, MgO trace, Na_2O 3.91, K_2O none, SiO_2 2.39, Al_2O_3 0.91, H_2O^+ 3.49, H_2O^- 6.00, sum 99.92%. Spectrographic analysis showed small amounts of Pb, Zn, Mo, Cu, Zr, and Mn. The analysis corresponds to $\text{UO}_3:\text{As}_2\text{O}_5+\text{P}_2\text{O}_5:\text{Na}_2\text{O}+\text{CaO}:\text{H}_2\text{O}=2.0:1.0:0.97:5.2$, with $\text{Na}_2\text{O}:\text{CaO}=2:1$. The mineral dissolves readily in dilute acids or in Na_2CO_3 solution. A D.T.A. curve shows a strong endothermal effect at about 200° .

The mineral occurs in fine, tabular to elongated crystals with lengths up to 1.5–2 cm., as radial fibrous aggregates, and as square crystals pseudomorphous after metazeunerite (sometimes with a core of metazeunerite). Crystal faces are corroded and could not be measured. Color yellow-green to lemon- and straw-yellow. Luster vitreous, pearly on (001). Cleavage (001) perfect, (010) and (100) distinct. Hardness $2\frac{1}{2}$. G. (pycnometer) 3.846. Optically anomalously biaxial, neg., 2V very small, with $ns \alpha$ 1.585, γ 1.612. Sometimes weakly pleochroic with X colorless, Y and Z yellowish. Luminesces strongly yellow-green in ultra-violet light. X-ray study shows the mineral to be tetragonal with $a_0=7.12$, $c_0=8.61$ (not stated whether A. or KX), $c/a=1.2092$. Unindexed x-ray powder data are given and compared with those of Mrose. The strongest lines are 8.48 (10), 3.68 (10), 3.292 (9), 1.837 (9), 1.987 (8), 1.634 (8), 5.45 (7), 2.673 (7).

The mineral occurs in the oxidation zone of a primary hydrothermal deposit containing pitchblende, arsenopyrite, pyrite, and galena in carbonatized Devonian felsite-porphry and tuffaceous breccia. Oxidation caused the formation of realgar, orpiment, scorodite, mansfieldite, metazeunerite, troegerite, and arseniosiderite. Sodium uranospinitite is the most abundant secondary U mineral. It is sometimes replaced by uranophane. Arseniosiderite forms pseudomorphs after the uranium micas. The locality is not given, as usual.

A member of the meta-autunite group, known as a synthetic compound (Mrose, *Am. Mineral.* **36**, 322 (1951), **38**, 1157 (1953)).

M. F.

NEW DATA

Anthoinite

ERNST NIGGLI AND EMILIE JÄGER. Untersuchungen an Anthoinit. *Neues Jahrb. Mineral., Abhandl. (Festband Hans Schneiderhöhn)* **91**, 35–40 (1957).

Anthoinite was described in 1947 as $Al_2O_3 \cdot 2WO_3 \cdot 3H_2O$ (*Am. Mineral.* **33**, 385 (1948)). Study of type material shows it to be a valid mineral. Electron microscope pictures show tabular crystals up to 3 microns in size. Birefringence was noted under high magnification, n 1.81–1.82. A D.T.A. curve shows a large endothermic reaction at 515° , a large and sharp exothermic reaction at 620° , and a small exothermic reaction at 820° . The powder pattern has many lines, including strong ones (in A.) at 4.195, 3.070, 3.052, medium ones at 5.66, 3.979, 1.936, 1.862. These could not be indexed on an orthorhombic cell, but were indexed, not entirely satisfactorily, as monoclinic, with a_0 9.33, b_0 8.17, c_0 13.68 Å, β $95^\circ 40'$. The mineral may be triclinic.

M. F.

Scarbroite

W. J. DUFFIN AND J. GOODYEAR. X-ray study of scarbroite. *Nature* **180**, No. 4593, p. 977 (1957).

Scarbroite was described by Vernon (*Phil. Mag.* **5**, 178 (1829)) as a soft white material with G. 1.48 containing Al_2O_3 42.75, SiO_2 7.90, H_2O 48.55, Fe_2O_3 0.80%. It has since been generally considered to be a mixture of clays with an aluminum oxide. Material from vertical fissures in sandstone at South Bay, Scarborough, was re-examined. It is white, compact, fine-grained, and quite soft. Spectrographic analysis shows aluminum and silicon (the latter shown by x-ray to be present largely as quartz) and only traces of other elements. G. approx. 1.85, mean n 1.509. The x-ray patterns are slightly variable and somewhat diffuse. The strongest lines are 8.64 (10) (broad), 4.32 (8), 1.430 (8) (broad), 6.52 (7), 5.97 (7), 4.72 (7), 3.71 (7), 2.219 (7), 1.450 (7), 8.30 (6), 5.00 (6), 4.44 (6), 4.29 (6), 3.48 (6), 2.816 (6), 2.443 (6), 2.360 (6); 27 other lines are given. The pattern is tentatively indexed with a

hexagonal cell with $a_0=34.5$, $c_0=17.3$ Å, the 8.74 Å line being 0002. Heating to 120° for 2 days or dehydration over P_2O_5 changed the pattern slightly, probably due to a small reduction in c . On heating to 130–140° a different pattern is obtained which is indexed as hexagonal, with $a_0=31.0$, $c_0=12.8$ Å. Further heating causes the x -ray reflections to become more diffuse and fainter, and the c -axis shrinks to 11.3 Å at 228°. Heating at higher temperatures breaks down the structure completely, no x -ray pattern being obtained up to 900°, where a diffuse pattern of gamma- Al_2O_3 was obtained.

Further work on this apparently new aluminum oxide hydrate is in progress.

M. F.

Kettnerite

LUBOR ZAK AND VL. SYNEČEK. Bismuth minerals from Krupka (Graupen) in the Krušné Hory (Erzgebirge). *Univ. Carolina, Geol.* **3**, No. 1, 1–46 (1957) (in Czech with English summary).

Additional data (see *Am. Mineral.* **42**, 121 (1957)) are given. Microchemical analysis on about 0.1 g. gave Bi_2O_3 67.9, CaO 8.3, CaF_2 10.6, CO_2 12.6, H_2O 0.5, sum 99.9%, corresponding to $(CaF)(BiO)CC_3$. Spectrographic analysis showed very little Pb, and traces of Al, Cu, Fe, Mg, Mn, and Si. Rotation and Weissenberg photographs gave space group $P4/nmm$, a_0 3.79 ± 0.02 , c_0 13.59 ± 0.03 Å, c_0/a_0 3.59, c/a (goniometric) 3.57. The mineral occurs as 0.2–0.3 mm. plates on quartz or fluorite. The forms {001} (predominant), {111}, and {10·10} were observed. Hardness "not too high." Optically uniaxial negative, or biaxial with very small optical angle, $n_O > 2.05$. The strongest x -ray lines and intensities are 2.89 10, 1.732 9, 1.589 9, 1.893 8, 1.200 8, 2.104 7, 1.278 6; 16 other lines are given. The mineral is closely related to bismutite $(BiO)_2CO_3$ and beyerite, $Ca(BiO)_2(CO_3)_2$.

M. F.

Häggite

H. T. EVANS, JR. and MARY E. MROSE. The crystal structures of three new vanadium oxide minerals. *Acta Crystallographica* **11**, 56–58 (1958).

Black crystals separated from a drill core in sandstone from Carlile, Wyoming, gave x -ray patterns corresponding to two minerals, one closely related to doloresite, the second a new mineral. It is monoclinic, space group C_{2h}^2-C2/m , $a_0=12.17 \pm 0.05$, $b_0=2.99 \pm 0.01$, $c_0=4.83 \pm 0.02$ Å, $\beta=98^\circ 15' \pm 5'$. The unit cell contains $H_8V_4O_{10}$, as deduced from the structure (no chemical analysis). The formula may be written $V_2O_3 \cdot V_2O_4 \cdot 3H_2O$ or $V_2O_2(OH)_3$.

The name is for Professor Gunnar Hägg, University of Uppsala, Sweden.

M. F.

Frolovite

E. S. PETROVA. A new hydrous calcium borate-frolovite. *Zapiski Vses. Mineralog. Obshch.*, **86**, 622–625 (1957) (in Russian).

The mineral occurs in limestones of Middle Devonian age in the Novo-Frolovsk contact-metasomatic copper deposits, Tur'insk region, northern Urals. It is associated with calciborite (*Am. Mineral.* **41**, 815 (1956)), calcite, garnet, and magnetite, and replaces calciborite.

The color is white with a grayish tint, luster dull, translucent in fine splinters. Hardness 3.5, brittle. G. 2.14, Luminesces violet in cathode rays (calciborite luminesces green). Optically biaxial, positive, n_s alpha 1.572, gamma 1.586, both ± 0.003 , 2V about 75°, birefringence 0.014. Extinction sometimes undulatory.

Analysis by T. A. Zvereva gave B_2O_3 34.20, CaO 28.70, MgO 0.72, H_2O (cryst.) 32.96,

SO₃ 1.78, Fe₂O₃ 0.10, SiO₂ 0.57, sum 99.03%, which corresponds, after deducting about 3% gypsum, to CaB₂O₄·2.5H₂O. Spectrographic analysis showed also about 0.1% As, Zn, Sr, and about 0.01% Mn, Ti, Nb, Cu, P, V, Yb. The mineral is insoluble in water, easily soluble in warm acids. A DTA curve showed an endothermal effect at 190°, corresponding to the loss of water of crystallization.

Unindexed α -ray powder data by G. A. Sidorenko are given. The strongest lines and intensities (A., KX?) are 6.084 (10), 3.858 (9), 3.471 (8), 2.357 (8), 2.522 (7), 2.330 (7), 2.654 (6), 2.036 (6); 15 additional lines are given.

The name is for the locality.

DISCUSSION

Petrova does not mention that J. H. van't Hoff synthesized some fifty years ago two distinct modifications of CaB₂O₄·4H₂O. The α -ray powder data given are close to those found in the laboratory of the U. S. Geological Survey on a sample synthesized at 70° by Dr. W. T. Schaller, which corresponds to van't Hoff's β —CaB₂O₄·4H₂O. Dr. Schaller informs me (private communication), that he measured α 1.563, β 1.572, γ 1.586, 2V 70°, birefringence 0.023. This suggests that Petrova's α was really the β index.

The mineral is not close to any known and probably belongs in Class 25 of Dana's System, 7th Ed., Vol. II, near pinnoite.

M.F.

Smirnovskite

I. F. GRIGOR'EV and E. I. DOLOMONOVA. Smirnovskite—a new mineral of the group of hydrous fluoro-silicophosphates of thorium. *Zapiski Vses. Mineralog. Obschch.*, **86**, 607–621 (1957) (in Russian).

The mineral occurs in cassiterite-feldspar-quartz veins of the Etykinsk deposits, eastern Transbaikalia, in two distinct generations, associated with quartz, amazonite, topaz, zinnwaldite, fluorite, and especially with cassiterite.

Two complete and two partial chemical analyses are given:

	1	2	3	4
ThO ₂	51.20	59.0	—	53.11
TR (a)	7.90	0.84	—	2.22
CaO	3.90	4.10	1.82	2.70
MgO	0.22	0.21	0.40	none
Na ₂ O	1.00	—	—	—
K ₂ O	1.00	—	—	—
Fe ₂ O ₃	1.05	2.80	8.00	0.70
Al ₂ O ₃	0.79	2.87	—	—
SiO ₂	6.54	9.75	10.00	3.96
P ₂ O ₅	17.80	9.01	—	17.02
F	5.02	3.58	—	—
H ₂ O ⁺	6.87(b)	9.25	—	—
U ₃ O ₈	0.10	—	—	—
	103.39(c)	101.41	—	—
—(O=2F)	2.09	1.41	—	—
	101.30	100.00	—	—
G.	4.68	—	—	—

Analyst	T. L. Pokrovskaya	L. B. Tumilovich	T. L. P.	A. Y. Sheskol'skaya
Color	Dirty-brown	Mixed	Dirty-brown	Pale Brown

(a) Presumably TR_2O_3 . (b) Penfield method. Another method gave 5.40 (c) Given as 102.39.

These give (Th, Ca, Ce)(P, Si, Al)(OH)(O, OH, F)₄ with P:Si=66:29 in No. 1 and 37:47 in analysis 2. These are compared with the analyses of auerlite (Dana's System, 6th Ed., p. 489, 1027); smirnovskite differs in the higher content of P_2O_5 , rare earths, and F. Spectrographic analyses showed also Ba, Pb, As, Mn, Sn, and Sr.

The mineral occurs in square to diamond-shaped (in cross-section) crystals up to 1.5 cm. in diameter. The color is mostly reddish- to dirty-brown, also orange, yellow, colorless. Luster greasy, fracture conchoidal, hardness near 5. G. 4.68 (dirty-brown). Mostly isotropic with n 1.702–1.718 (brown or red), 1.685 (colorless); anisotropic reddish-brown material had n_s 1.678, 1.682 and were uniaxial positive. The birefringence of some crystals was up to 0.015.

A D.T.A. curve shows an endothermic effect at 100–280° and a small exothermic effect at 600–700°.

The mineral is metamict, giving only a few diffuse lines. When the mineral was heated at 800° for 4 hours, it gave good pattern of thorianite with a_0 5.56 Å. A similar mineral is noted from pegmatites of eastern Kazakhstan. It is uniaxial, positive, n 1.664, birefringence 0.018. It contains no rare earths.

The name is for the late Sergi S. Smirnov.

DISCUSSION

This is apparently a phosphate-rich metamict thorite or thorogummite. The differences from auerlite do not seem to me to be sufficient to justify a new name.

M.F.

Jagoite

RAGNAR BLIX, OLOF GABRIELSON, and FRANS E. WICKMAN. Jagoite, a new lead-silicate mineral from Långban in Sweden. *Arkiv. Mineral., Geol.*, **2**, 315–317 (1957).

Jagoite is a rare mineral found around 1943 in hematite ore in the "Cambera" stope. It occurs as fine-grained micaceous aggregates of plates, commonly surrounded by a zone of black melanotekite. Other associated minerals are quartz and an unidentified mineral.

Analysis (by R. B) gave SiO_2 22.35, BeO 0.12, Al_2O_3 0.50, Fe_2O_3 7.00, TiO_2 0.10, MgO 0.60, FeO none, MnO 0.88, CaO 0.65, PbO 64.26, Na_2O 0.61, K_2O 0.37, Cl 3.25, H_2O^+ 0.17, H_2O^- 0.19, F none, active O none, sum 101.05—($\text{O}=\text{Cl}_2$) 0.73, 100.32%. This corresponds to $(\text{Pb}, \text{Ca}, \text{Mn}, \text{Na}, \text{K})_{24}(\text{Fe}, \text{Al}, \text{Mg})_7(\text{Si}, \text{Al}, \text{Be})_{27}\text{O}_{84}(\text{OH}, \text{Cl})_8$.

Jagoite is yellow-green, streak yellow. Luster vitreous, shining on cleavage surfaces. H. 3, G. 5.43. Non fluorescent in ultra-violet light. The mineral is optically uniaxial, negative, refringence around 2.0, birefringence 0.025. Non-pleochroic.

Laue photographs show jagoite to be trigonal. Oscillation, rotation, and equi-inclination photographs were of poor quality because the plates of jagoite are easily deformed. The hexagonal unit cell has $a_0=8.65\pm0.03$, $c_0=33.5\pm0.1$ Å, possible space groups $P3$ and $P\bar{3}$. Cleavage (0001) perfect. Unindexed x-ray powder data are given; the strongest lines are 3.40 (10), 2.80 (8), 4.16 (5), 2.99 (5), 2.50 (4).

The name is for John B. Jago, mineral collector, of San Francisco.

M.F.

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